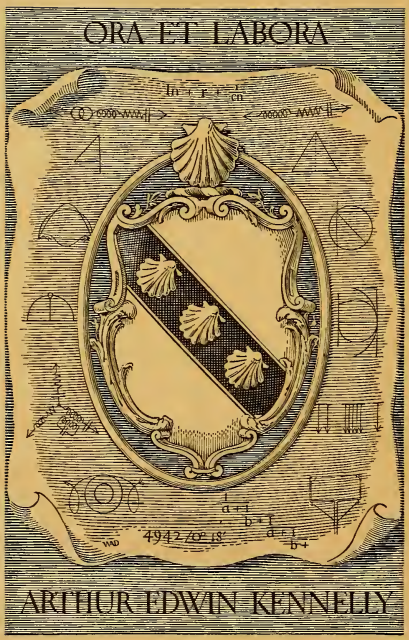
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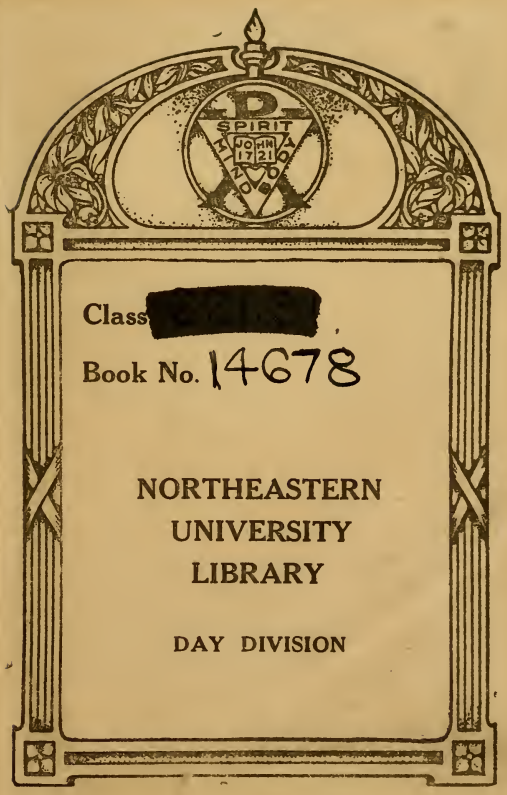

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BY
JOHN F. C. SNELL

VICE-PRESIDENT OF THE INSTITUTION OF ELECTRICAL ENGINEERS, MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS (WATT GOLD MEDALLIST), MEMBER OF THE INSTITUTION OF MECHANICAL ENGINEERS, MEMBER OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, MEMBER OF THE INSTITUTION OF MUNICIPAL AND COUNTY ENGINEERS, MEMBER OF THE NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS, FELLOW OF THE GEOLOGICAL SOCIETY, PAST PRESIDENT OF INCORPORATED MUNICIPAL ELECTRICAL ASSOCIATION, MEMBER OF THE ENGINEERING STANDARDS COMMITTEE, MEMBER OF THE IRON AND STEEL INSTITUTE, ETC., ETC., ETC.

WITH 17 FOLDING PLATES AND 186 ILLUSTRATIONS

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PREFACE

The Author ventures to hope that the principles and information given in this book, together with the typical examples of modern power houses shown, will be of some use to his engineering brethren, whether civil, mechanical, electrical, or mining engineers.

He does not claim to have introduced any noticeable originality, but rather to have drawn upon his own experience, and to have collected and classified the experience of other and more eminent engineers. By condensing this information in a practical form in one book, an endeavour has been made to give all the requisite practical information on power-house design, and thus to save the loss of time which results from searching through numbers of text-books, proceedings of Institutions, and the admirable descriptions of power houses in the Technical Press. The information selected has been carefully sifted out by the Author's experience gained in various power stations over a period of more than twenty years, and especial care has been taken to avoid errors and to preserve exactitude.

The Author desires to express his indebtedness to Messrs. H. W. Kolle; J. H. Rider; C. Stanley Peache; Leonard Andrews; S. S. Moore Ede; J. Shepherd; B. M. Jenkin; Belliss and Morcom; Browett, Lindley & Co.; British Westinghouse Electric and Manufacturing Co.; Galloways, Ltd.; Dick, Kerr & Co.; E. Green & Sons; Herbert Morris and Bastert; Balcke & Co.; Oscar Böving & Co.; British Thomson-Houston Co.; The Interborough Rapid Transit Co.; to the Institutions of Electrical Engineers and Mechanical Engineers, American Inst. of Elec.

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JOHN F. C. SNELL.

July, 1911.

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INTRODUCTION

Power houses for the generation of electrical energy are now indispensable in all industrial or civic requirements. The Author will endeavour in this work to give reliable and up-to-date information on their design and equipment, whether required for the supply of power, light, and other purposes within cities or over more scattered but wider areas, as for power distribution to mines, groups of collieries and various works, for suburban or other railway services, tramways and light railways, or smaller independent power houses and sub-stations for large factories.

In order to cover adequately so wide a survey it will be necessary to enunciate certain principles and to establish certain data for the guidance of the designer. Power houses with steam, oil, or gas prime movers will not only be dealt with, but also hydro-electric plants. It is neither proposed to trench on the province of other text-books dealing with the fundamental principles of thermodynamics, electrotechnics, or hydraulics, nor with the design of the prime movers and electrical machines, but rather to assume a certain knowledge of these, and at once to proceed to their adaptation and to the elements of successful power house design and operation.

The design of all power houses must depend on several conditions, such as—

(*a*) The nature of the service for which energy is to be supplied.

(*b*) Environment, or the position of the site and accessibility to water, fuel, length of transmission, climatic conditions, and geographical position.

(*c*) Commercial requirements from the undertaking.

(*d*) Probabilities of future development.

No engineer would, for example, lay down a low-pressure

direct-current plant for the supply of a large area having a radius of several miles, neither would a water-power plant be installed if the cost of embankment and pipe line, with the capital charges resulting therefrom, were greater than the cost of, say, steam-turbine plant dependent on fuel which, though, in that particular case, costly, would result in less annual costs either in the immediate or in the ultimate service required. Nor would a three-phase high-pressure system be adopted in a compact area which could be more economically dealt with by a simple direct-current system, unless there were special reasons (as may happen in the case of mines) where alternating current motors may be preferable, and where a gradually extending radius of supply has to be considered. These and many other points have to be taken into account when considering the design and types of plant to be adopted for any particular duty. It is because the future success of industrial undertakings, both at home and abroad, depends so much on the skilful judgment exercised in the selection of this fundamental system of supply—in the special adaptability of the system adopted to the requirements of the district, factory, mine, or whatever it may be—that a book of this nature may prove of use to engineers, especially to those who in some out-of-the-way corner of the globe may be called upon to furnish a power house without an opportunity of obtaining advice from some expert in this branch of engineering, and also to civil engineers in their ever-increasing reliance upon electrical auxiliaries.

The essential problem is to provide a power house and electrical system at a minimum capital cost consistent with good and durable engineering work, together with subsequent minimum resultant working costs.

The design of the power house cannot be considered apart from the whole undertaking, and the designer has to bear in mind the transmission lines or feeders, as well as the nature of the load and the load factor. It would be of little use designing the most economical power house, and then to neutralize the economy so gained by an undue expenditure on cables and other apparatus.

CHAPTER I

SYSTEMS

THE recommended standard voltages and frequencies in Great Britain, America, and Germany are given in Table No. I.

TABLE I.

	American practice.		British practice.		German practice.	
	Volts.	Frequency.	Volts.	Frequency.	Volts.	Frequency.
Direct current . .	125	—	110	—	115	—
	250	—	220	—	230	—
	550–600	—	440–500	—	470–550	—
Alternating current .	2,200	25	2,200	50	1050	25 or 50
			3,300	50	2100	do.
	2,200	60	6,600	50	3150	do.
			11,000	50	5250	do.
Transmission circuits	6,600	either		—	—	—
	11,000	do.	—	—	—	—
	22,000	do.	—	—	—	—
	33,000	do.	—	—	—	—
	44,000	do.	—	—	—	—
	66,000	do.	—	—	—	—
	88,000 and higher	do.	—	—	—	—

NOTE.—Exception is made in British practice where the circumstances demand a lower frequency, in which case a standard of 25 periods per second is adopted.

Thus, in American practice, with a terminal voltage of 2200 in alternating current distribution, there can be either a step-down transformer ratio of 1 to 10 or 1 to 20 for distribution, and a step-up ratio for transmission with direct multiples of the generator terminal voltage, viz. 3, 5, 10, 15, 20, 30, 40, and higher. A range of terminal voltage from standard voltage at no-load to

10 per cent. over the standard figure is recommended to cover the drop in the transmission circuit.

In British practice the terminal voltage is usually 6600 with step-down ratios of 1 to 30, and occasional cases of step-up ratios of 66 to 110 or 66 to 220.

Each system has its uses, and it would be beyond the scope of this book to enter into more than a general comparison of them. It is impossible to lay down specific rules, as each system must be considered in relation to the general service required, length of transmission, average load factor, source of power, and other factors.

It is now universally recognized that the standard systems and pressures for power-house generators are as follows:—

TABLE II.

System.	American.		British.	
	Voltage.	Frequency.	Voltage.	Frequency.
(*a*) Three-phase	2200	25	6600	25
(*b*) ,, ...	2200	60	6600	50
(*c*) Single-phase	—	15	6600	15
(*d*) ,, ...	—	25	6600	25
(*e*) High-pressure direct-current* . .	not fixed	—	not fixed	—
(*f*) Low-pressure direct-current . .	250	—	220	—
(*g*) do.	550	—	440	—

* The maximum pressure adopted on the Thury system has been 7200 volts per generator on the Moutiers-Lyon transmission scheme, which has a total line pressure of 57,600 volts.

(Two-phase systems are little used, and do not compare favourably in economy with 3-phase systems, so that they are excluded.)

In the case of higher pressures than 11,000 volts, it is customary and advisable (except in special cases of direct current as in the Thury system) for the power-house generators to work at 6600 or smaller pressures, and to step up this pressure to the higher-line pressure, otherwise the design of the machine, voltage per slot, etc., increase the cost and are less safe than with a lower pressure machine, and oil-immersed, step-up transformers. In the Author's opinion 6600 volts is a reasonable maximum which he would wish to see universally standardized for power-house

generators. There would then be only four standard pressures required (excepting the special case of high-pressure direct-current), viz. :—

Recommended systems to be chosen—

(*a*) Three-phase	25 ~ 6600 volts.
(*b*) Three-phase	50 ~ ditto (60 in America).
(*c*) Single-phase	25 ~ ditto.
(*d*) Direct-current	440 volts.

As stated above, the fundamental system must be made to suit each particular district, or local requirement, so long as a standardized pressure and frequency are adopted, but they may be generally classified as under—

1. Railways.—Either single-phase overhead line construction at high pressure, the present practice ranging from 3000 volts to 11,000 volts, or direct-current third rail at about 600 volts. In some American cases the distributing pressure is 1200 volts.

Both of these transmission systems may, and probably would, be independent of the power house—that is, in the former, while it would fix the frequency, the pressure at the generator terminals could be independently fixed; and in the latter the generators would almost certainly supply 3-phase 25 ~ currents to local rotary sub-stations. A load factor of 40 per cent. may be taken as a fair average for railway work, but each case will, of course, have to be worked out in detail.

2. Power Supply over Large Areas.—3-phase 50 ~. In such a case the power-house voltage would be fixed at 6600 stepping up where necessary for long transmission-lines. An average load factor of 25 per cent. may generally be counted upon.

3. General Supply to Large Cities.—A 3-phase 50 ~ system supplying rotary sub-stations for direct-current distribution, or a 3-phase, 4-wire, low pressure distribution system through step-down transformers. Load factors of about 22 per cent. may be expected.

4. Smaller Towns.—Where a 3-phase supply is not warranted by the probable future requirements of and radius of supply within any town, then the simple direct-current system at 440 volts should be adopted. The economical area of supply for such a direct-current system is about $1\frac{1}{4}$ mile from the power house.

An average load factor of about 15 per cent. is usual, without tramways supply and in a non-industrial district.

5. Collieries and Mines. — 3000 volts 50 ~. A 3-phase system is generally adopted on account of the greater safety of alternating motors in mines liable to fire-damp or dust, and as it affords facility for extension. Mines usually give an annual load factor of some 40 per cent., including ventilation, pumping, hauling, winding, etc.

6. Rolling Mills.—American practice has largely led to the adoption of direct-current plant, whereas English and Continental practice is in favour of 3-phase plant. More will be said of this in the special chapter devoted to this class of power plants. The average annual load factor is about 20 per cent.

7. Textile and Grain Mills, etc. — Three-phase 50 ~ 3-phase motors have an immense advantage over other types on account of the absence of commutation and the practical elimination of any chance of ignition of the fine dust usually found in such mills, and also on account of the constant speed so necessary in textile mills. Textile mills have an annual load factor of some 30 per cent., while paper and grain mills give a load factor of about 80 per cent.

8. Shipyards, Arsenals, and Similar Factories. — Though in many existing cases direct current has been adopted, 3-phase motors are being more generally used, and have considerable advantages in exposed positions, as in shipyards and wharves, and they require less attention. In all new works, therefore, a 3-phase system will probably be adopted. The average load factor is only from 18 to 22 per cent.

9. Chemical Works.—For metallurgical processes, as in the manufacture of carbide and similar products, alternating current with a frequency of 50 ~ is invariably adopted. For the preparation of acids, alkalis, dyes, and so forth, direct current at a pressure of 100 volts is normally required. All these works usually have an extraordinarily high load factor, sometimes over 90 per cent., and the machinery must therefore have a generous rating as regards temperature, with a fair instalment of stand-by plant to allow for repairs and inspection.

10. Docks, Jetties, and Wharves.—Owing to the exposed positions

of capstans and jib-cranes, 3-phase motors are recommended. Care must be taken to deal with, and if necessary to correct, the low power factor which is often experienced in such cases. Very low load factors are common, sometimes as low as 2·5 per cent.

11. Thury High-pressure Direct-current System.—This system has been adopted in several cases in Europe for long-distance transmission, the most notable cases being the 27,000-volt line between St. Maurice and Lausanne, and the Moutiers and Lyon line, with a 112-mile transmission at 57,600 volts. In this system the generators are run in series (eight 7200-volt generators being in series in the Lyon case), and one of the generators has to bear the maximum difference of pressure between line and earth (the earth being made use of as a return conductor). It would be impossible to insulate the windings of such a machine practically, so the whole machine is insulated from earth, frame and windings alike, the armature being coupled to the engine or turbine by an insulated coupling. Special attention has also to be paid to the safety of the attendants, and so the whole engine-house floor is also insulated, and the protection is such that it is impossible for any employé to touch the machines and "earth" simultaneously. The engine-house floor has generally been constructed of a thick layer of asphalte concrete with an additional thin layer of pure asphalte, the machines being further protected by carriage on insulators.

CHAPTER II

PRELIMINARY NOTES ON THE CHOICE OF SITE AND TYPE OF PLANT

The system and the generator pressure and frequency having been determined, the next question to settle is the type of plant to be adopted, *i.e.* whether steam, gas, oil, or water. The last-named, of course, is rarely available in Great Britain, and, as it involves special consideration altogether, this may be left to the special chapters devoted to hydro-electric plants.

The utilization of waste furnace gases in steel works where enormous wastage has gone on in past years, is another special case, which is separately dealt with later (see Chap. VIII.). Gas engines are usually adopted, though in some cases the gases are used to raise steam in specially arranged boilers.

Small independent plants often adopt oil engines, and reference is also made to them in a later chapter (VIII.). A rapid development is now taking place, and Diesel engines of 6000 H.P. are already being built.

In general practice, at present, the choice lies between steam and gas. If the former be settled upon, then there is a choice between turbines and reciprocating engines, though in practically all but very small powers, turbines are now universally fixed in newer power houses, on account of their greater economy in capital and in steam, and the smaller space occupied. A combination of both types of prime mover, *i.e.* steam and gas, in large power houses has much to recommend it.

The points for consideration in determining between gas and steam are—

(*a*) Average daily load factor of plant output and size of unit of plant.

(*b*) Cost of fuel.

(*c*) Possible market for ammonium sulphate.

(*d*) Relative cost of generating plant and buildings.

(*e*) Geographical position of power house.

(*a*) **Load Factor of Plant.**—Generally speaking, the higher the load factor the better the case for the gas engine, especially if there be a market for the sulphate of ammonia recovered. The higher the price of fuel, the better, also, is the relative economy of the gas engine. The general thermal efficiency of modern steam-raising plant is only about 12 per cent., whereas the thermal efficiency of the internal combustion engine is about 25 per cent. Considerations of capital cost, of course, have to be made, the latter being more costly.

Gas engines are now working regularly up to 4000 H.P., and great development has taken place in their design in recent years.

Area required.—In the matter of area required by steam or gas plant there is little to choose. The following Table (No. III.) will give, approximately, the area required for stations ranging from 10,000 to 120,000 K.W., provided the boilers are all on the same plane (and not arranged on two decks, as in the case of some large power houses), and the figures include coal silos for the larger stations. The variations in the figures (which are taken from actual examples) is accounted for by the different designs adopted.

TABLE III.

STEAM PLANTS.

Plant installed.	Type of unit and power house.		Natural circulating water supply.				Cooling towers for circulating water.			
K.W.	Single deck = S.D. Double deck = D.D.		Area per H.P.		Area per K.W.		Area per H.P.		Area per K.W.	
			Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.
13,000	Reciprocating	S.D.	0·331	0·278	0·444	0·371	0·407	0·340	0·546	0·455
60,000	do.	do.	0·192	0·160	0·257	0·215	0·223	0·186	0·299	0·250
10,000	Turbines	do.	0·164	0·137	0·221	0·185	0·263	0·220	0·353	0·295
28,000	do.	do.	0·121	0·101	0·162	0·135	0·162	0·135	0·217	0·181
48,000	do.	D.D.	0·136	0·114	0·183	0·153	0·173	0·145	0·232	0·194
120,000	do.	S.D.	0·151	0·126	0·203	0·169	—	—	—	—

Gas Engine Plants.

Plant installed.	Type of unit.	With ammonia recovery plant.				Without ammonia recovery plant.			
		Area per H.P.		Area per K.W.		Area per H.P.		Area per K.W.	
K.W.		Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.	Sq. yds.	Sq. metres.
1000–12,000	Horizontal	0·746	0·623	1·000	0·836	0·620	0·518	0·831	0·695

Water Supply for Condensing Plant and other Purposes.—If possible, of course, the power house should be laid out with a good river, canal, or sea frontage, so that not only can circulating water be obtained easily and cheaply, but also that fuel can be water-borne and ashes easily disposed of. The consumption of water will be as follows (average conditions of humidity being taken for the cooling towers):—

TABLE IV.

Climate.		Per B.H.P. hour.		Per K.W. hour.	
		Natural supply. Gallons.	Cooling towers. Gallons.	Natural supply. Gallons.	Cooling towers. Gallons.
Steam.	Temperate	57·4	7·0	89·0	10·9
	Tropical	71·4	8·4	112·0	13·3
Gas.	Temperate	7·75	1·0	10·4	1·4
	Tropical	12·0	1·6	16·0	2·25

Care has to be taken to arrange the circulating pipes so that they will not be liable to damage by shipping, and with due regard to the rise and fall of spring tides, and so that they will not silt up with mud and débris. This will be dealt with in detail later in the special chapter devoted to the design of pipe work and condensers (Chap. VII.).

Feed-water Supply.—If the geological strata are such as to provide not only a good foundation, but also a supply of good feed water through sinking an artesian well or a bore-hole, the site will be more valuable, since the cost of pumping such water is usually only one-sixth, or less than the cost of purchasing the water, and

moreover dispenses with evaporating plant and reagent apparatus which would be necessary were brackish or salt water used from which the circulating water is obtained.

Accessibility for Coaling.—Regard must be given to railway sidings or to wharfage and tidal facilities for coaling. The average annual amounts of coal which have to be dealt with for large stations are as follows (based on an average calorific value of 13,500 B.Th.U.):—

TABLE V.

Load factor.	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.	Tons per annum.	Tons per diem, average.
	Twenty per cent.		Thirty per cent.		Forty per cent.		Fifty per cent.		Sixty per cent.	
Steam plant per 1000 K.W. installed	2740	7·5	3800	10·5	4700	13·0	5400	15·0	6000	16·5
Gas plant per 1000 K.W. installed	1200	3·3	1825	5·0	2360	6·6	3100	8·5	3600	9·9

In many stations situated abroad, or in places where coal can be more economically borne in large steamers, or where by reason of geographical position coal can only be intermittently delivered, space has to be found for bunkers and for coal silos of sufficient capacity to provide adequate reserves. Regard must also be paid to maximum temperature, depreciation of coal, and prevention of spontaneous combustion. This matter is dealt with under the special section devoted to Steam-raising Plant (see Chap. IV.).

Foundations.—Attention must be given to the foundations of the proposed site and to the contour of the ground. Riverside sites are, as might be expected, often on alluvial flats, and borings must be taken to ascertain the nature of the substrata and their capability of carrying heavy weights. Concentrated weights up to 15 tons per square foot have to be arranged for as in the case of main stanchions carrying the dead load of the roof and an overhead crane with live loads. A good bed of stiff clay, marl or compact gravel—provided there is no underlying stratum of sand

—will make an excellent foundation. In some cases, however, the site may be covered with alluvial mud or sand, when it will be necessary to drive piles into the underlying subsoil and to float the site with a concrete raft. Such a procedure is costly but may be justified by the other advantages accruing from the position. In large stations the wharfage or jetties for unloading coal and other materials may also represent a large capital expenditure.

Buildings.—Care has to be exercised in fixing the datum line of power houses. The relation to the water level of the condensing water supply, whether sea, river, or lake, has to be fixed, especially in tidal rivers or estuaries. The limits of spring and ebb tides fix (*a*) the levels of the condenser pipe line, and (*b*) the levels of coal jetties and also of the engine-room. Upon these in turn depend the excavation necessary on the site and therefore the cost of the building. This necessary excavation as a rule clears away the softer material overlying the site and enables a firm foundation to be obtained; and in many cases excellent gravel and sand can be reclaimed for use in the concrete required for foundations or reinforced walls. The cost of approach roads has in some cases to be borne—and in others a cable tunnel for some distance out from the power house. There are many other considerations, such as the cost of local stone, or bricks, cement or relative cost of reinforced concrete. For power house construction, especially if of large capacity, a steel work structure with filled-in panels of brick or of concrete, is as a rule desirable and cheaper. The boiler-house structure requiring to carry large overhead bunkers and the engine-room stanchions, the roof principals, large cranes and switchboard galleries, a strong and at the same time a cheaper construction can thus be obtained. Especially in the case of power houses in remote districts abroad is this desirable, provided there is no insuperable or commercial difficulty in transport of the heavy stanchions and members to the site.

Future Development.—In laying out a power house it is well to look some way into the future and design at once what is estimated to be the total requirements, even if only a small part is immediately to be built. The Author has learnt from experience the necessity of doing this, and now always prepares a key plan for the whole site and ultimate complete plant from which the

detailed plans for the first section are prepared. It is true that subsequent development may modify the original lay-out in some details, as in the use of larger units, but as the capacity of the site is really limited by the space available for steam-raising or gas-producing plant, the principal points of the original design need not be impaired by subsequent development.

Size of Units.—The nature of the work, and the average load factor have to be considered as well as the reliability factor. It is well so to arrange the sizes of engines and boilers or gas producers that the estimated daily load curves may fit in with the units of plants installed in such a way that they may be run as nearly as possible at rated, or at the most economical, load. A further consideration in the case of large steam stations lies in the relative number of boilers requisite to each prime mover. An ideally simple arrangement is, of course, one boiler to each engine or turbine (or in a gas plant, one set of producers to each engine) for this simplifies the pipe work and reduces the cost of the power house equipment. But as boilers are restricted in size, for reasons of economy and ease of handling, etc., this arrangement necessarily limits the available size of engine to, say, 1500 H.P. as a maximum.

Such an arrangement is shown in Fig. 1 and cannot be improved upon for very small stations and independent power plants.

The next step is to double-bank the boilers (as shown in the illustration of the Greenwich power house of the London County Council, Plate I.). Here the size of the engine may be doubled, thus arranging that one line of boilers and one engine and condenser may, together, form one complete set. The size of engine is then raised to 3000 or 4000 H.P. This arrangement is good for medium sized power houses.

A further development may be made in arranging the lay-out so that four or more boilers and one turbine may together form one set. This is shown in Fig. 2, where the turbine axis is shown at right angles to the boilers so as to reduce the engine-room span and the cubical contents of the buildings.

A further development still can be obtained by arranging the boilers on two floors. This method is adopted where the site values are very expensive and greater than the increased expense of the somewhat extravagant buildings entailed. This has been

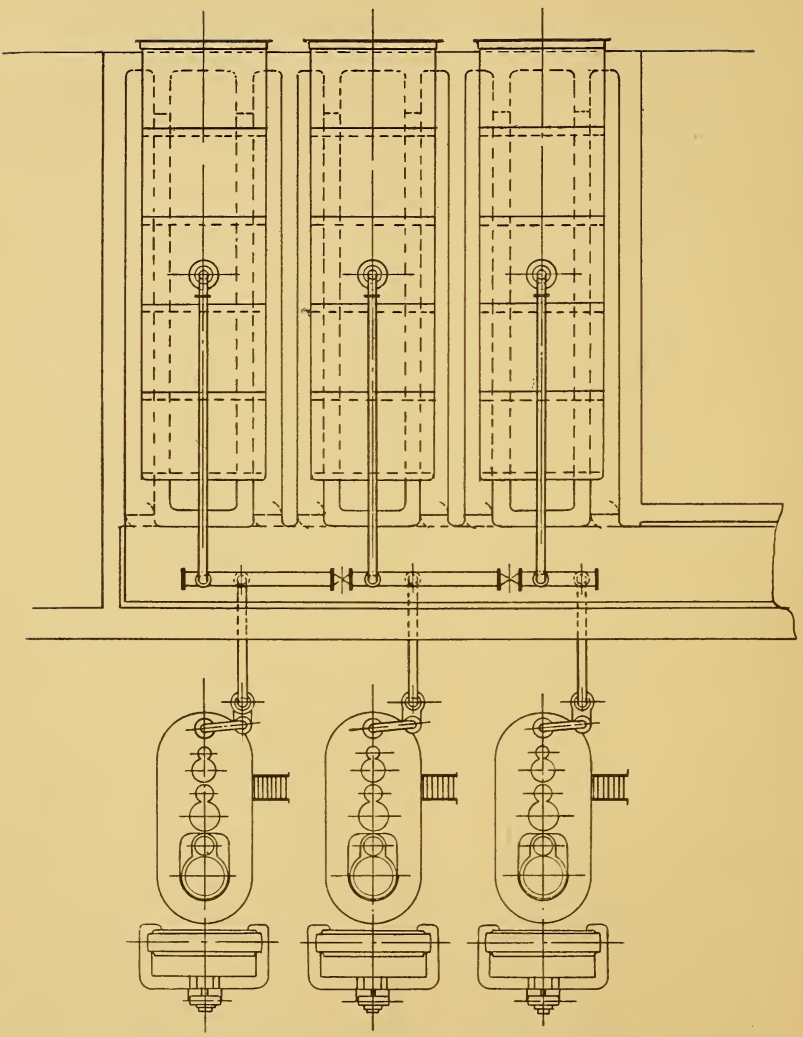

Arrangement of One Lancashire Boiler
to each 500-600 K.W.
Scale of Feet.
0 5 10 15 20 25

Fig. 1.

done at the Chelsea power house of the Underground Railways of

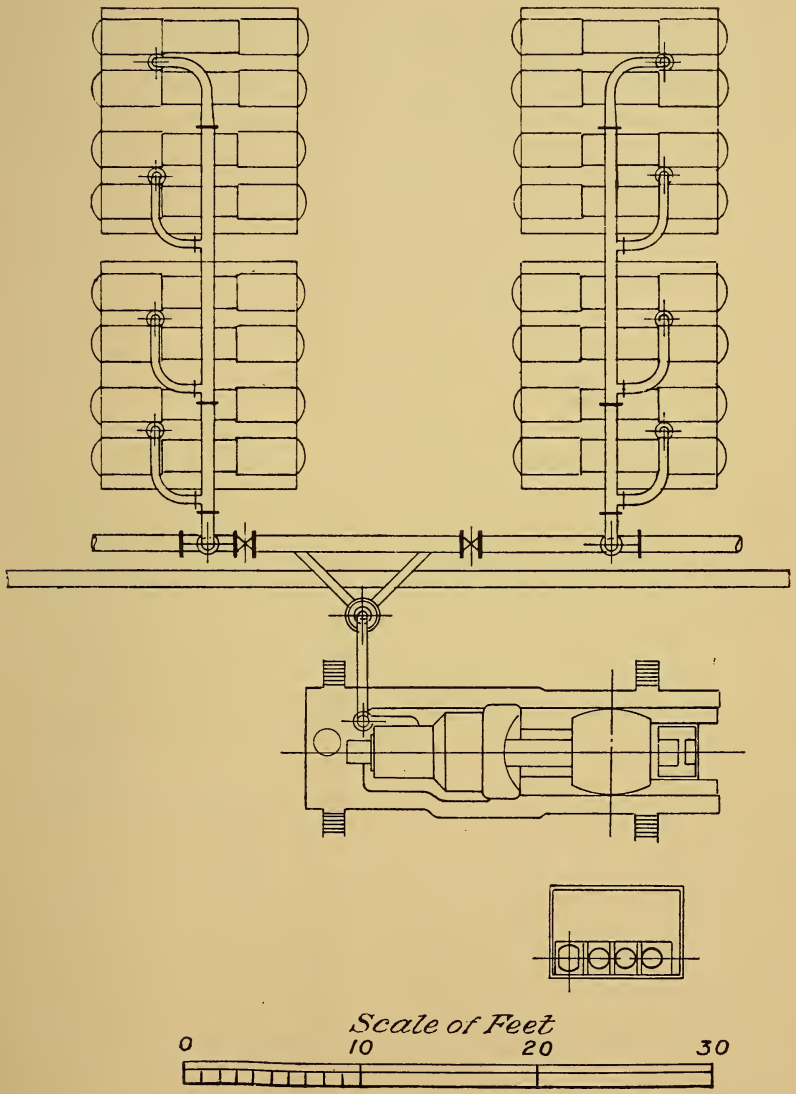


Fig. 2.

London (as shown in Fig. 3) and at the Interborough Rapid Transit Company's Manhattan Power House in New York (see

Plate II.), and other places. The Manhattan power house is now supplemented with exhaust turbines.

For still larger stations and those of the largest types a completely different design must be made. In such cases the boiler house is laid off with a double bank of boilers and with the requisite number to supply steam to the single large turbine fed

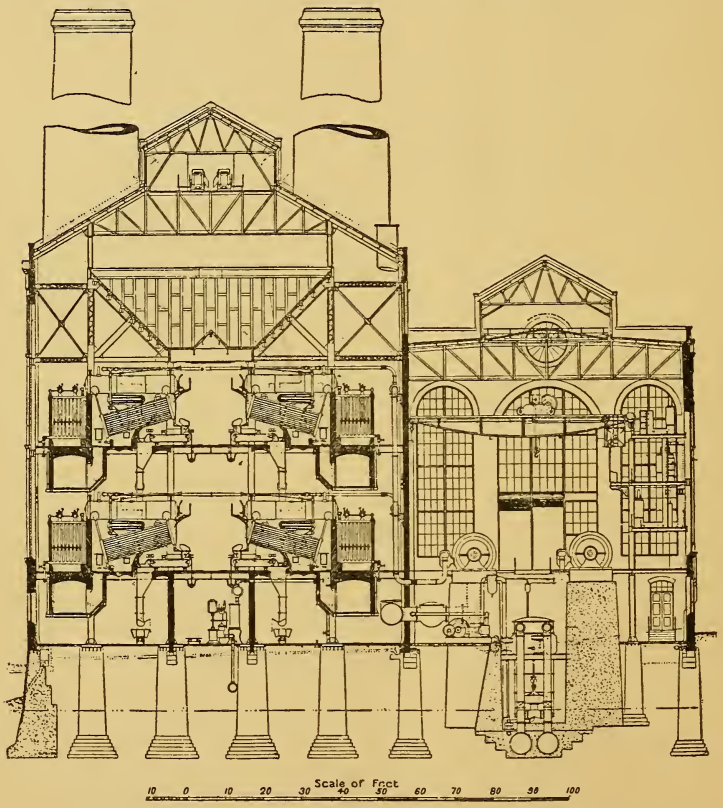
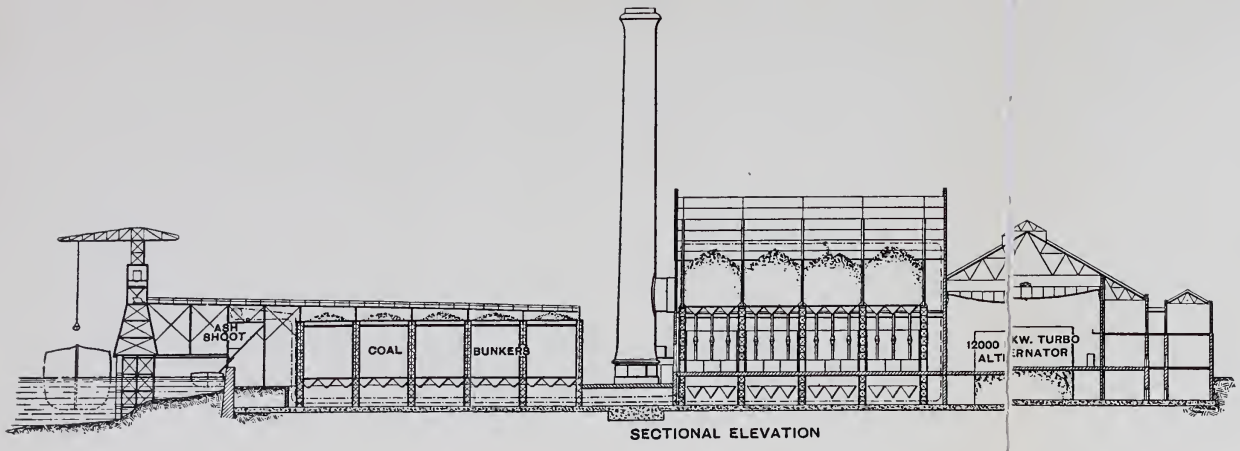
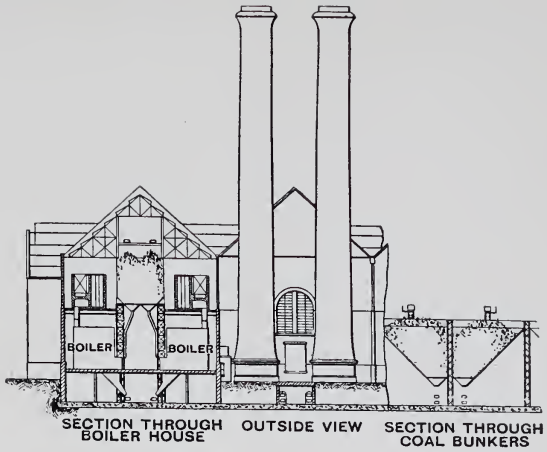


FIG. 3.

from them. This boiler house, complete with its one or two stacks and induced draught fans and pumps, together with the single turbine and its condenser, form one complete unit of plant in the power house and is known as the cellular or bulkhead principle. This is of great importance in a large power house, as in the event of an explosion or other disaster the danger of a complete shut



SECTIONAL ELEVATION

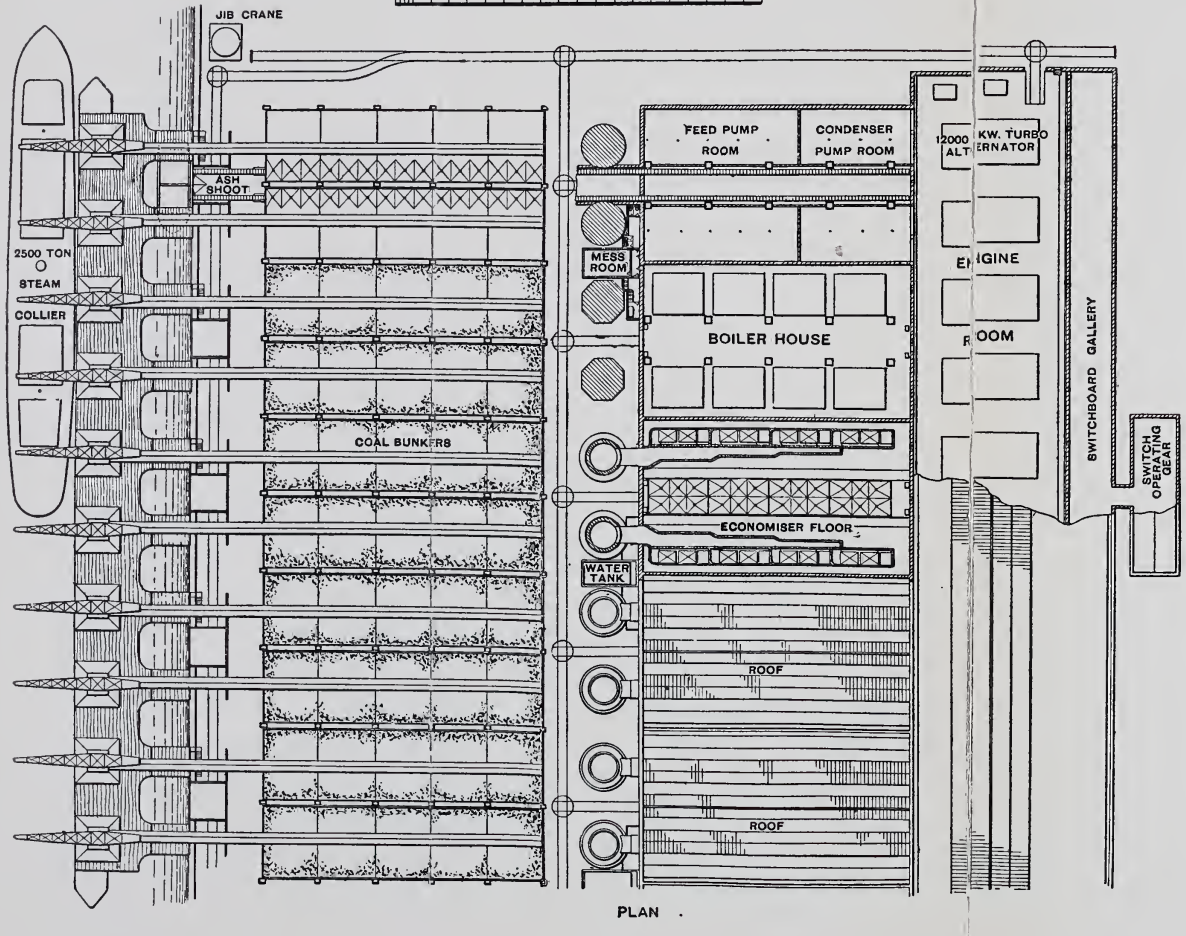


SECTION THROUGH BOILER HOUSE

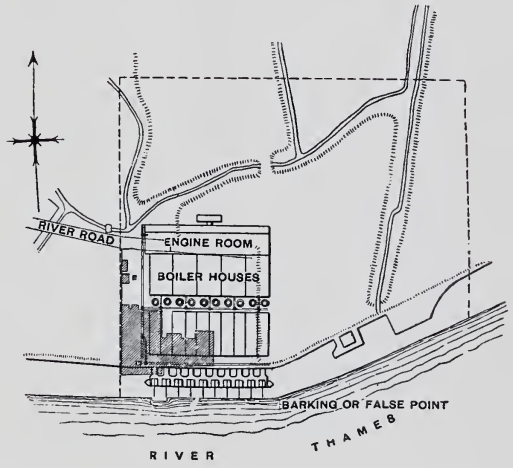
OUTSIDE VIEW

SECTION THROUGH COAL BUNKERS

Scale of Feet
0 50 100 150 200



PLAN



PLAN OF SITE

Scale of Feet
0 200 400 600 800 1000

PLATE III.—PROPOSED POWER HOUSE AT BARKING CREEK, DESIGNED FOR BULK SUPPLY TO THE COUNTY OF LONDON.

[*To face page* 17.

down is minimized. An illustration of this design is shown in Fig. 4, and in the illustration of the large power house in Buenos Ayres constructed by the German Transatlantic Electricity Company shown in Fig. 5.

The Author would advocate the extension of this principle to the switchgear, so arranging it that each separate generator and its auxiliaries is self-contained and the whole switch gear fixed in a separate switch house with collecting cables led to two separate control houses from which the transmission lines would radiate and in which the operator would control the whole system by a master keyboard and relays. This is dealt with later in the special chapter on Power House Switchgear (Chap. X.).

Plate No. III. should be referred to for the lay-out of the 120,000-K.W. power house proposed to have been built at Barking Creek, designed for the bulk supply to the County of London. The arrangement of coal-handling plant, self-contained boiler ranges, shaft and turbine as one complete unit, as well as the switch annexe, may be specially noted. It may be interesting to compare the carefully prepared estimates of the cost of this power house which are set out in Table No. VI.

TABLE VI.

RATED OUTPUT OF POWER HOUSE, 120,000 K.W.; OVERLOAD, 150,000 K.W.

Item.	Capital cost.	Cost per K.W.	
		Rated load.	Overload.
	£	£	£
Land	50,000	0·41	0·33
Buildings	344,000	2·87	2·30
River work and pier	102,000	0·85	0·68
Coal and ash plant	59,000	0·49	0·40
Boilers and economisers	199,000	1·66	1·33
Pipework and pump	105,000	0·88	0·70
Turbo-generator and condenser	430,000	3·58	2·86
Switchgear, etc.	67,000	0·56	0·44
Engineering expenses and contingencies	115,260	0·96	0·77
Total	£1,471,200	£12·26	£9·81

Ideal Number of Units of Plant.—Eight complete units of plant have many advantages. In this way the power house can be worked so that one set is always allowed to be dismantled, another

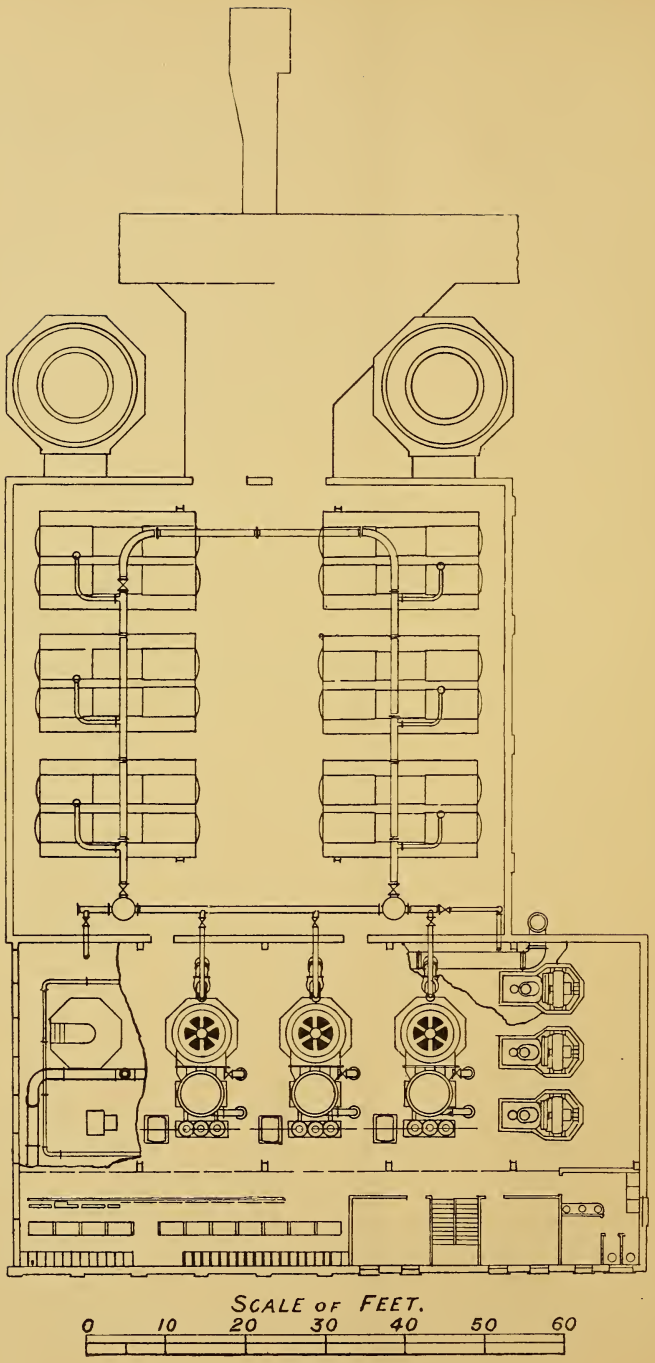


FIG. 4.

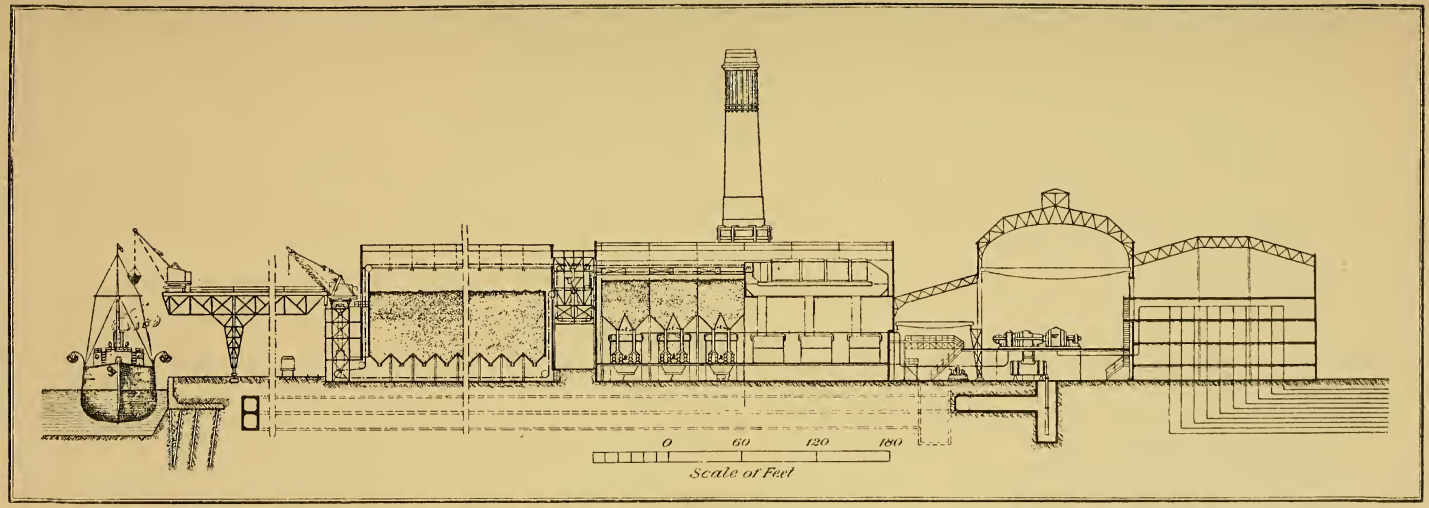


Fig. 5.

set in reserve, and six sets in commission, at rated load. Since each set will be so designed as to be capable of developing a 25 per cent. overload for several hours without undue strain or temperature rise, there are in reality two sets in reserve for emergency. Thus the safe rated load of such a station would be six while the capital expenditure would be on eight only, or 33 per cent. in excess of the rated and commercial output, and the reserve would be two sets with a third out of commission. But the safe output would really always be seven either working at rated load or with six working on overload for the necessary time, so that the capital invested in reserve plant is thus only 14 per cent. of the whole. In special cases of metallurgical or chemical applications where very high annual load factors are experienced, then no doubt the proportion of reserve plant would have to be increased, and, as a rule, the number of complete units would be smaller than eight. For general applications on a large scale, however, there is much to be said for this principle.

Standardization.—In designing a power house it is of great importance to standardize as far as possible. Having determined the most useful size and type of plant, boilers, pumps, condensers, or gas plant, as the case may be, auxiliaries and switchgear, it is quite easy to arrange interchangeability of sets and of parts. Thus, in the case of water-tube boilers the spare tubes, fire bars, superheater tubes and bricks can be reduced by arranging for all boilers to be uniform in size and type, spare pistons and valve rings, governor parts, brasses, eccentric straps, oil pumps and motion gear, or even spare cranks can be easily carried as part of the equipment in a reciprocating engine installation or spare blades, wheels, nozzles, governor parts, oil pump and other accessories in the case of a turbine plant; spare tubes and ferrules or air pump parts for the condensers, spare feed pump parts; spare valves for the pipe range; spare switches and instruments, insulators, etc., for the switchgear. All this reduces capital expenditure, saves room and cost of repairs, and makes things more orderly in the administration of the power house. This means a great deal, especially when the situation is a remote one as in the colonies or a foreign country where spare materials take a considerable time to be delivered when ordered from a

distance. More will be said of this when dealing with the particular parts of the power-house equipment. In British practice it is becoming increasingly the vogue, and very properly so, to adopt the standards prescribed by the Engineering Standard Committee, when by adopting standard pipe flanges and bends, for instance, right through, there are never any bastard sizes of joint rings or odd bolts and nuts to be kept in stock.

Simplicity of Design.—The Author has elsewhere remarked that "simplicity is the hall-mark of good design." Speaking as one who had for many years the control of public supply stations, the Author cannot too strongly urge the importance that should be attached by the designer to a *simple* lay-out of any power house. This applies more particularly to the pipe work and auxiliaries, arrangement of flues, dampers, and switchgear. It also, of course, applies to the design of the various parts of the plant itself. Accessibility for inspection of boilers, removal of soot from flues, ready handling of parts of engines and condensers, or cleaning and inspection of switch equipment is essential. Avoid any "cranks" in the design, and, though progress will never be made unless some engineers are courageous enough to try new inventions, they should only be adopted (or well tried and proved types should only be departed from) after a most careful investigation.

After these preliminary and general remarks, the various sections of the power house and types of plant can be dealt with in practical detail.

CHAPTER III

BUILDINGS

Architecture of Power House Buildings.—Considerable differences occur in the architecture of large power houses in various countries. In America generally towns are planned or set out in squares or blocks, which make it difficult to obtain large sites within the city. The price of land is high as a rule. When the power house is situated within the town, the practice is to adopt a rectangular building covering the part of or the whole of one block. The most is made of its value, and a considerable installation of plant is obtained by arranging the plant in several decks or stories. In the case of other intra-mural stations in other countries, a good deal has to be expended on architectural features, such as stone facings or ornamental stone and moulded work, so as to make the structure harmonize with the surrounding buildings, and thus not detract from the amenities of the district in which it is built. Further, the increasingly stringent building bye-laws of various cities, and the great precautions which have to be taken against vibration, noise, smoke or steam nuisance, all increase the cost of foundations, shafts, etc.

On the other hand, when the power house is erected at a distance from the city, the same regard has to be paid neither to ornamentation nor to possible litigation from nuisance. This does not mean that an ugly structure need be erected, for a well-designed building need not be unnecessarily expensive, and regard can be paid to a nicety of architectural design. The engineer must make the outline design and lay-out of the power house, leaving the architect to clothe the structure and co-operate with the engineer on the question of foundations.

One of the designer's initial problems is, therefore, to determine

the differences in capital outlay between an ornate building situated on a more costly site (but near the network or load the plant contained within it is to supply), which may roughly be calculated at 9*d.* per cubic foot, or £3 5*s.* per K.W., and a less costly building situated at a distance from the city, to which must be added the cost of the transmission mains plus the cost of a receiving sub-station or switch-centre for distribution. Such an outside station in some districts may have the walls raised only to engine-room level, and covered in with galvanized iron sheets above. Also he must calculate and balance the extra cost of coal carriage to the inside site, removal of ashes (and in some cases additional cost of water and circulating pipes, or even cooling towers and the extra ground they occupy), as against the extra transmission losses from, and the reduced efficiency of, the outside power house system.

As an instance of the wide difference between modern conditions and those of only a few years ago, there are no less than thirty-eight public supply houses within the County of London, involving an expenditure of £3,500,000 on buildings and land alone, to accommodate some 160,000 K.W.—or £21·9 per K.W. installed. The Engineering Board, of whom the Author was a member—who advised the London County Council from 1905 to 1907—designed a 120,000-K.W. power station situated down the river Thames, the land and buildings for which were estimated to have cost £394,000 (or £3·28 per K.W. available within the county after transmission), and proportion of transmission lines, as well as the various sub-stations, about £1,000,000, or a total of £1,394,000 (£11·6 per available K.W.) as against the £21·9 cited above.

Foundations.—The question of foundations enters largely into the design of power houses, and affects the disposal and distribution of the heavy loads. These are principally concentrated on the stanchions carrying the bunkers and stanchions of the engine-house with heavily loaded travelling crane. Some three-quarters of the whole load is concentrated on one-half of the site, the turbines, etc., making up the remaining quarter load being distributed over the other half. The effect of vibration is thus increased greatly, and in some cases, with reciprocating engines, there are difficulties in preventing this vibration from being transmitted to a distance,

more especially when the site covers compressible or water-logged soils. When such sites are compulsory, reinforced piles may be driven either over the whole site, or at points of concentrated load such as under stanchions, and bound together with a reinforced concrete raft, so as to increase the carrying capacity of the soil and to prevent it from exuding or working out from under the foundations, and also to reduce the tendency to increase any vibration or to transmit it to a distance. In some cases of internal power houses—especially those built on alluvial strata—expensive concrete basement structures have to be adopted, and these are to be avoided wherever possible, as they increase the cost of a building enormously, with, as it were, nothing to show for it.

As has been said before, there is the further consideration that long lines of large pipes or concrete culverts have to be laid from the power house to the source of the condensing water supply, as it is almost impossible commercially to use cooling towers in such instances.

Altogether, therefore, the modern tendency, rightly, is to go outside a city and to choose a site—for whatever purpose the power house is required—where land is cheaper, building easier, and coal accessible, with the additional facility of a plentiful supply of circulating water. For gas-driven power houses an outside site is absolutely necessary. The established development of high-tension 3-phase supply has made the choice of sites much less confined to a small area, so that there is in all modern instances a greater freedom in the choice of sites, with a resultant economy in negotiations for the purchase of land in a suitable locality.

In the Manhattan Railway Company's power house, New York, there is room to house 150,000 H.P. The site is 560 feet by 204 feet, or 12,700 square yards in extent and 66 feet from parapet to the top of granite base. The building consists of a skeleton steel structure, with double decks, with heavy enclosing walls, the base being of granite, and with brickwork above, covered in with a red-tiled roof. The windows are all in the upper parts of the building, and are very large, being 45 feet high by 14 feet wide and spaced 35 feet apart, thus giving good light. The engine-room is 93 feet wide by 128 feet long by 107 feet in height, containing eight 10,000-H.P. reciprocating engines, the height of

each being 42 feet from foundation to top. Each steam generator weighs 400 tons.

Contrast this with a turbine installation of like units, especially with regard to the height of the engine-room, which could easily have been reduced to 60 feet, thus entirely remodelling the design of the power house and enormously reducing its cost. The boiler house is 104 feet wide by 128 feet long by 128 feet in height, and contains bunkers with a storage capacity of 15,000 tons, carried on stanchions spaced 20 feet apart longitudinally and with 15-foot centres transversely. Each stanchion carries a load of 500 tons. There is a total of 6000 tons of steel used in the structure, or 75 tons per 1000 K.W. capacity of station. The maximum working stress on the steel throughout on the whole design is taken at 6 tons per square inch, thus giving a factor of safety of 4 to 5. In this case there are four brick circular shafts, each 278 feet high by 17 feet internal diameter at top, carried on octagonal bases 73 feet from the ground level. The Manhattan power house is built on an uneven foundation of gneiss rock, and therefore of unequal supporting power. Considerable variation in the thickness of the concrete foundation was therefore necessary so as to distribute the weight.

As power houses frequently have to be erected on river-side sites, the subsoil is usually not suitable for such heavy weights without some assistance. A careful adjustment of the weight is necessary, since the alluvial soil will resist in some places and yield in others. When it is soft or water-logged the superincumbent load should be carried on concrete floats proportionate to the loads carried, and rather more than one and a half times the thickness or strength which would be taken for an ordinary building of similar size. This is good practice on clayey soils. The concrete float should, however, be keyed on the underside on sand and looser soils.

At the Calcutta power house, where the soil is an alluvial mud—soft and compressible—a continuous concrete float was adopted, and carried a load of 1 ton per square foot without appreciable settlement.

In Amsterdam the same plan was adopted, but in that case the subsoil was first consolidated by driving piles, placed so

as to take up the loads brought down designedly to various points.

At Bahia Blanca, where the soil is a water-logged sand 10 feet 6 inches in thickness, lying on marl, the Author and his colleagues adopted reinforced concrete piles, driven into the underlying marl, and concentrated the piles under the main stanchions and engine foundations, floating the whole with a concrete raft, reinforced with old steel rails. Fifteen tons per square foot was concentrated on the stanchion foundations.

At the Kingsbridge power house, New York, the subsoil is a fine sharp sand. In this case some 15,000 oak piles 40 feet long were driven 28 inches from centre to centre, and a raft of concrete 8 feet thick was then laid over the whole site, mixed in the proportion of: cement 1; sand 2; stone 4 parts.

The maximum bearing weight in this case is also 15 tons per square foot. Another multiple-deck station is shown in the illustration of the Edison power house at Philadelphia (Fig. 6). This is, as shown, an eleven-storey building, with two boiler decks, a separate generator deck, and an engine basement. Such power house designs are to be avoided, however, and a comparison with Plate I. will show the great difference between, and the great improvement in, the design of a modern installation.

The weights usually allowed for in designing the structures and floors (in addition to the weight of floors themselves) are as follow—

Boiler-house firing floor . .	1120	lbs. per square foot
Engine-room floor	1120	,, ,,
Switchboard galleries . . .	336	,, ,,

Safe Carrying Power of Foundations.—The following Table, No. VII., gives the load-carrying power of various subsoils :—

TABLE VII.

Subsoil.	Load-carrying power.
	Tons per sq. foot.
Hard rock	250
Compact gravel	4
Ordinary or confined sand	2
Hard clay or chalk	4
Soft clay and wet or loose sand . . .	1·0

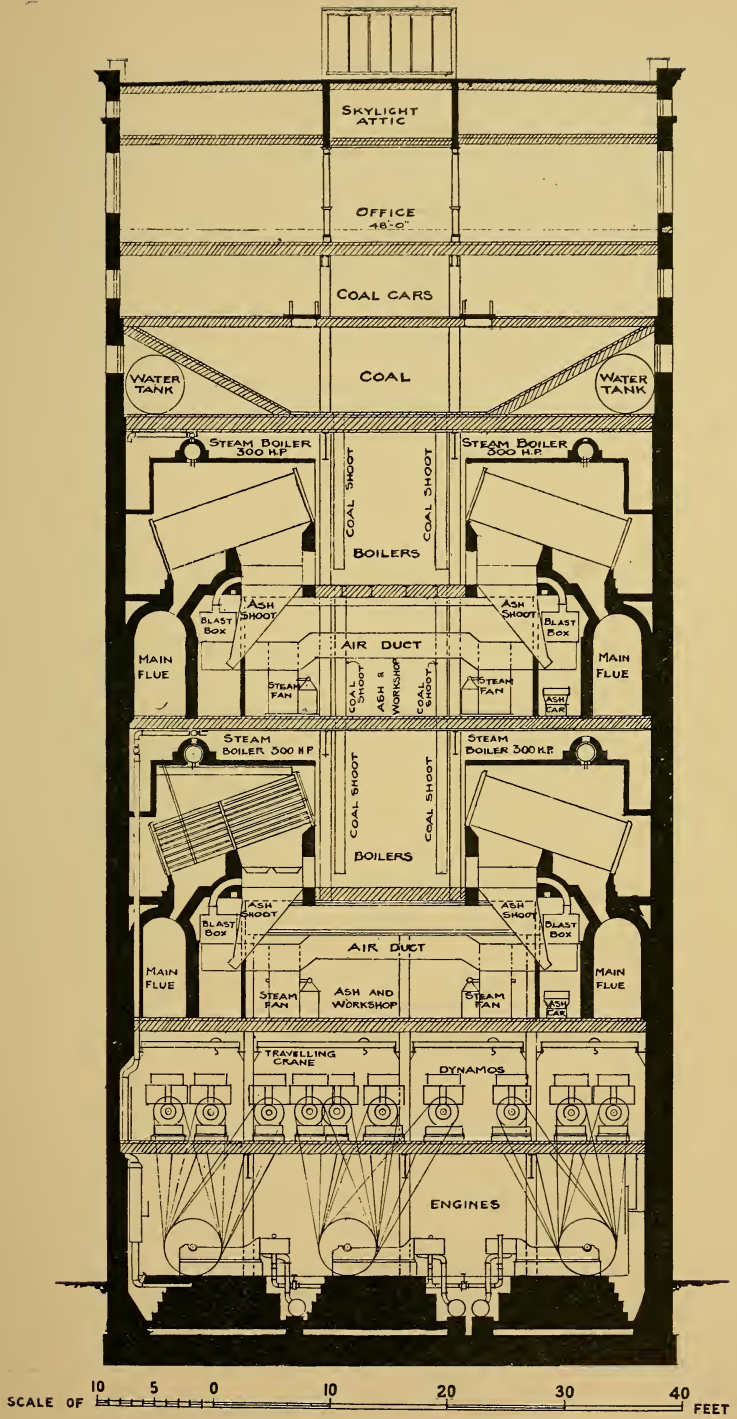


FIG. 6.—Sketch—Cross-section.

In yielding or water-logged soils, piles of reinforced concrete must be driven, with a concrete float or raft overlaid on them.

Rankine gives the following formula for the greatest deadload a pile will bear without further sinking :—

$$P = \sqrt{\left(\frac{4ESWH}{L} + \frac{4E^2S^2D^2}{L^2}\right)} - 2\frac{ESD}{L}$$

where W = weight of ram or monkey,
H = height of fall of same,
D = depth driven by last blow,
S = sectional area of pile in square inches,
L = length of pile in feet,
E = modulus of elasticity of material of pile.

The machinery foundations must be entirely separate from the main walls so as to minimize or eliminate vibration. Firm foundation subsoils such as clay and rock transmit vibration easily which may reappear at some distance from the power house. Looser subsoils do not transmit vibrations so readily. For turbine work no real difficulties exist, but with reciprocating engines special care must be taken not only to have good substantial concrete blocks with widened and extended bases, but in some extreme cases a layer of sand, or of hair felt, or of indiarubber, is necessary. The following safe loads on foundations may be used :—

TABLE VIII.

Nature of foundation.	Safe carrying load in tons per sq. foot.
Good concrete	4
Steel rails in concrete	8
Concrete piles	12
Ordinary bricks in cement mortar	5
Hard bricks ditto	8
Blue bricks ditto	12

Setting out Foundations.—Templates are used to set out accurately the positions of bolt holes for the machinery foundations. Holes should be left in the concrete to receive the foundation bolts with side holes at the bottom to give access to the plate and cotter. Removable wooden core-boxes are usually fixed while the concrete is being put in. The foundation block, when completed, should

be surfaced off in neat cement and strickled or stoned up to a true and uniform surface. When the concrete has set the machine is then lifted into position, set up on steel wedges, aligned and trued up, and the interstices run in with cement grout.

Fire-proof Buildings.—It is almost unnecessary to say that all power houses must be made non-inflammable; no wood should be used in the whole of the structure. Even to use wood shingling as ceiling boards is a grave mistake, since with high-tension switch-work there is a possibility of incandescent oil or flames being shot out to a great height, when such boards, necessarily as dry as tinder, will catch light with ease. The Author has found that a very good roof, non-inflammable and light, but strong, can be made of eternit sheets or ceiling boards, used as an inner lining to the roof, with slate or eternit outside roofing materials. A detail of this is shown in Fig. 7. The cost of this, excluding labour for erection (which would be similar in both cases) was 8*s.* 9*d.* per square yard, as against 6*s.* 9*d.* per square yard for ordinary slating and wood lining. Window frames should be of iron, but small doors can be of wood, as being from their positions unlikely to catch fire. Large doors can be of the Kinnear rolling type with advantage. The power-house site should be isolated so as to prevent danger from fire breaking out in, and spreading from, neighbouring property.

American Specification: Structural Steel. — The American standard specification for structural steel contains the following provisions:—

(*a*) The steel to be made either by the open hearth or Bessemer process.

(*b*) The steel not to contain more than 0·1 per cent. of phosphorus.

(*c*) The steel is divided into two classes, viz. (1) rivet steel, and (2) medium steel.

The following table gives the qualities specified:—

	Rivet steel.	Medium steel.
	Tons.	Tons.
Tensile strength	22·33 to 26·8	26·8 to 31·2
Yield point, not less than . . .	13·5	15·6
Elongation in a length of 8 ins. .	26 per cent.	22 per cent.

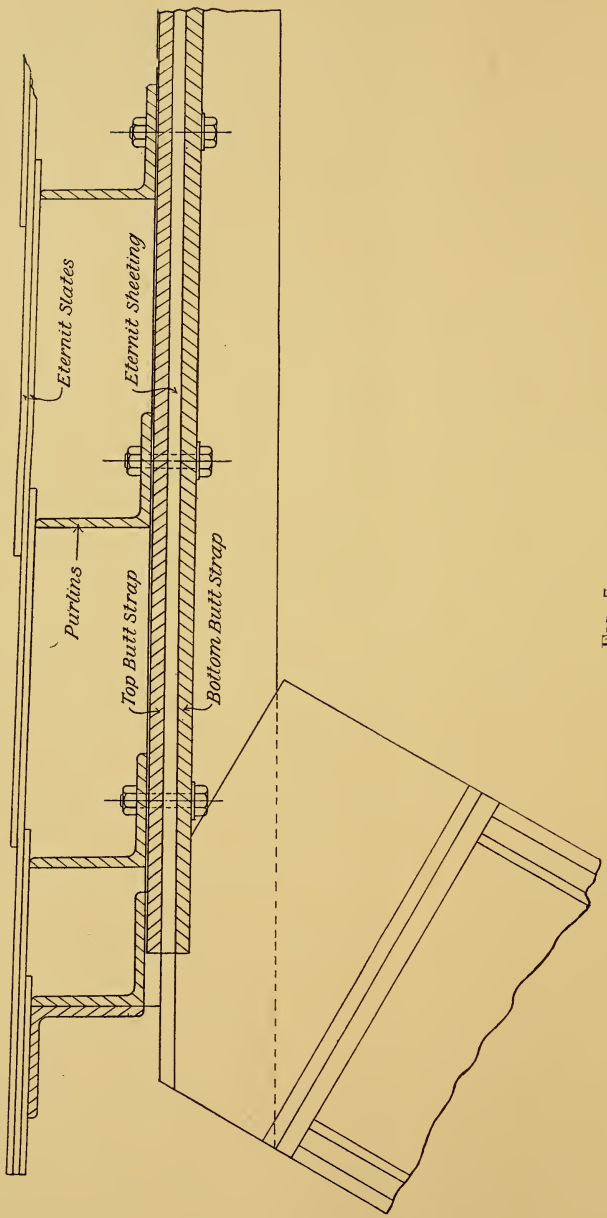

Eternit Slates
Eternit Sheeting
Purlins
Top Butt Strap
Bottom Butt Strap

FIG. 7.

Slight variations are permitted in materials less than $\frac{5}{16}$ inch and more than $\frac{3}{4}$ inch in thickness.

The following further tests are also specified:—

(*a*) The rivet steel to be capable of being bent cold 180° flat on itself without signs of fracture on the outer edges.

(*b*) The medium steel to be bent cold 180° around a diameter equal to the thickness of the specimen tested and without signs of fracture on the outside.

The low carbon steels usually answer to the following analysis:—

Carbon	from 0·17	per cent.	to 0·27	per cent.
Silicon	,, 0·02	,, ,,	0·09	,,
Phosphorus	,, 0·10	,, ,,	0·05	,,
Manganese	,, 0·05	,, ,,	0·07	,,
Sulphur	,, 0·01	,, ,,	0·04	,,

These steels, therefore, have similar properties to wrought iron, except that their strength is greater, their ductility is greater, and the fracture shows a fine silky and velvet-like appearance.

In compression the yield point is the same as that in tension. The shear strength is about four-fifths that of the tensile strength. They are, of course, affected by increase of temperature.

British Specification.—(*a*) All plates and bars to be made by the open hearth or Bessemer process, acid or basic, and not to show on analysis more than 0·06 per cent. of sulphur or 0·07 per cent. of phosphorus. An analysis of each cast is often required from the manufacturer.

(*b*) No plate or section to be more than $2\frac{1}{2}$ per cent. over, or $2\frac{1}{2}$ per cent. under, the calculated weight.

(*c*) The following properties are also specified:—

	Plates, angles, bars, etc.	Rivet bars.
Tensile strength	28 to 32 tons	26 to 30 tons
Elongation in length of 8 ins. .	20 per cent.	25 per cent.

For materials not less than $\frac{5}{16}$ inch in thickness bending tests only are required. With rivet bars bending tests are not required.

(*d*) In both cold and temper bending tests, the pieces to withstand without fracture being doubled over until the internal radius is not greater than one and a half times the thickness of the test piece.

The above are the leading particulars, and the designer is referred to the actual standard specification for further details.

No cast work should be used in steel structural buildings, owing to its unreliability. It is usual to calculate steel members so that the maximum stress, counting in all possible forces, such as dead weight of structure; wind pressure, calculated at 40 lbs. per square foot; and moving loads, such as the overhead crane loaded with maximum lift, bunkers, fuel, etc., shall not exceed 8 tons per square inch. This will give a factor of safety from 3 to 4 under a combination of the maximum stresses possible. It is also usual so to design the stanchion bases that the concentrated maximum load shall not exceed 15 tons per square foot on the foundations.

Weight of Steel Structure.—The weight of steel structures for power houses are as follows, the examples being taken from actual power house built to the Author's requirements :—

	Tons.
A. Structural steel work, including stanchions, girders, joists, roof principals, bracings, purlins, stairs, window-frames, doors, galleries, gulleys, and down pipes	562
B. Coal bunkers and ash bunkers, exclusive of stanchions included under A.	158
C. Steel chimney. (The bricks for lining and for base plinth weighing 44 tons)	26
Total	746

The above building enclosed an area 21,924 square feet and a volume of 1,096,100 cubic feet.

Generally speaking, the weight of steelwork necessary for power-house structures having overhead bunkers, condenser basement, and switchboard galleries, may be calculated at the following rates :—

Power House 5000 to 10,000 K.W.
- 150 tons per 1000 K.W. normal rating,
- 36 tons per 1000 square feet enclosed,
- 0·68 ton per 1000 cubic feet enclosed ;

reducing proportionately to—

80,000 to 100,000 K.W. { 75 tons per 1000 K.W. normal rating, 18 tons per 1000 sq. feet enclosed, 0·34 ton per 1000 cub. feet enclosed.

Brickwork.—In steel skeleton structures the wall panels can be either of concrete or of brickwork. These afford some measure of support to the steel stanchions, but the stanchions should nevertheless be calculated without this uncertain assistance. The walls merely have to sustain their own weight and the wind pressures on their surfaces.

The following thicknesses are required by the London Building Acts:—

TABLE IX.

Height.	Thickness.
30 feet	17½ inches reducing to 8½ inches
40 ,,	21½ ,, ,, 13 ,,
50 ,,	26 ,, ,, 13 ,,

The following is an extract from the London Building Act, 1894:—

"If in any storey of a building of the warehouse class the thickness of the wall is less than one-fourteenth part of the height of such storey, the thickness of the wall shall be increased to one-fourteenth part of the height of the storey and the thickness of each external wall and party wall below that storey shall be increased to a like extent, but any such additional thickness may be confined to piers properly distributed, of which the collective widths amount to one-fourth part of the length of the wall."

In the New York Building Laws it is specified that the thickness of walls shall be as follows in Table X., when the clear width of building is 50 feet:—

TABLE X.

Height of wall in feet.	First section.		Second section.	
	Height.	Thickness.	Height.	Thickness.
	ft.	ins.	ft.	ins.
40	40	24	—	—
60	40	28	Top	24
75	25	32	Top	28

The above is, of course, for plain brickwork structures and without steel framework. For practical purposes the former table could be better taken as a guide.

The brickwork footings are usually arranged twice the width of the lower walls.

It will be useful to point out that—

1 rod of brickwork = 272 super feet, $1\frac{1}{2}$ brick in thickness
= $11\frac{1}{3}$ cubic yards
= 4850 bricks on average work.
330 stock bricks = 1 ton in weight
„ „ = 55 cubic feet.

The crushing strength of bricks is as follows :—

London stock bricks	140 tons per square foot
Wire-cut bricks	260 „ „ „ „
Blue Staffordshire	360 „ „ „ „

The resistance to crushing of brickwork built in cement is about $\frac{1}{5}$ that of the bricks of which it is built.

Reinforced Concrete and Stonework.—The crushing strengths of various building stones are as follows :—

Sandstone	300 tons per square foot
Limestone	500 to 700 tons per square foot
Whinstone (basalt). .	1000 tons per square foot
Fine grain granite . .	1500 „ „ „ „

Stone structures are expensive, as a rule, but are requisite in some countries where these materials are more easily obtainable, or in some intra-mural power houses where the architectural features are of importance.

Reinforced concrete can be used with good effect for the wall-panelling between stanchions. The thicknesses of walls in such cases are usually as follows (extract from the London Building Acts) for steel skeleton-framed buildings :—

" **Thickness of Walls.**—Enclosing wall for topmost 20 feet of its height to be not less than $8\frac{1}{2}$ inches thick, remainder not less than 13 inches brickwork, terracotta, concrete, or other material to be executed in Portland cement-mortar, bedded close up to the metal

framework, without any intervening cavity, all joints made full and solid."

This is usually specified to be made in the proportion of 1 of Portland cement to 2 of sand and 4 of fine gravel, reinforced with steel wires No. 10 in thickness and interwoven. Portland cement will give not less than 400 lbs. per square inch when tested in briquettes after one week's immersion in water, and will improve with age. Tests of higher values are often obtained.

The compressive strength of cement is stated to be 150 to 250 tons per square foot, and the strength of various mixtures as in Table No. XI.

TABLE XI.

(POPPLEWELL.)

Mixture.		Compressive strength in tons per square foot.	
Sand.	Cement.	After 7 weeks.	After 20 weeks.
1	1	80	100
2	1	30	50
3	1	25	30
4	1	20	25
5	1	15	20

Good concrete depends on the cement used, composition of the aggregate, thoroughness of mixing, proportion of cement to aggregate, and on the age. Dr. Deacon found, in a series of tests in the great dam at Lake Vyrnwy, that the concrete used in that structure gave a compressive strength of 107 tons per square foot after one month, and 185 tons after 36 months. A reference may be made to the specification on page 75.

Interior of Power House Buildings.—Cleanliness, good ventilation, good lighting, and good drainage are essential. The boiler-house walls are usually left finished in neatly pointed brickwork, which, as a rule, is not glazed. Boilers, economisers, and exposed flue-walls should be finished in second quality white or cream-glazed bricks, not only for cleanliness, but especially to reduce air leakages through porosity as is dealt with in the chapter on boiler settings. The interiors of pump-rooms and engine-room should be

finished in glazed bricks, these usually being a brown or green brick up to dado height, with a string course to finish and white glazed bricks beyond. Arches are usually of coloured glazed brick to give the engine-room a pleasing appearance. If the stanchions are brick encased, the corners should be of bull-nosed bricks. Buttresses in smaller power houses are similarly finished. The joints should be then raked out and finished with Parian cement; this prevents lodgement of dust. Sometimes the insides are faced with glazed tiles, as in the case of reinforced concrete panels. The tiles should be keyed. The inside walls are sometimes finished smooth with Parian cement; this is not to be recommended, however, owing to its tendency to disintegrate and to stain if there be any trace of oil vapour in the air of the engine-room. The floors of the engine-room and switchboard galleries can be finished in limestone mosaic, which answers very well and is decorative, or in tiles. The boiler house should be paved with a hard stable brick, which will not chip easily, nor tend to disintegrate if hot ashes are pulled out on to the floor, and will wash down quickly. In condenser basements, the floor is usually finished in cement rendering. The concrete walls of the engine or turbine foundations can be finished smooth in cement. In some cases, where, owing to the exigencies of the site, some galleries are dark, the switchboard floor is finished in thick glass prisms set in a cast-iron framework, so as to allow passage of light to the gallery beneath. Stairways should be in iron, but with wooden non-slip treads, or they may be dangerous to employees. Storage battery rooms must be specially treated. The walls are usually left finished in first quality ordinary bricks. The floors can either be of hard bricks, similar to the boiler house, and laid with a good fall to several drainage gulleys, or laid with a similar fall in a special asphalte which must be acid resisting. Good ventilation is especially necessary, so as to prevent the acid fumes from escaping into the engine-room or other parts of the power house.

Ventilation of Power House.—A proper system of ventilation for the boiler house and engine-room is necessary. In the boiler house there is little trouble, owing to the doors, windows, and the ventilating louvres in the roof. Indeed, when the amount of displacement of air for necessary combustion of the fuel in the furnaces is considered,

the architectural details of the boiler house have to be considered carefully if only to provide comfort for the staff and prevent unnecessary draughts. (The special ventilation of generators is referred to in Chap. XI.) In the engine-room, however, this is more difficult. There should be no roof fan-lights, owing to the difficulty in keeping them weather tight and the chances of rain and snow driving in and dropping on the electrical plant. The engine-room should be thus arranged as loftily as is consistent with first cost, and clerestory windows operated from the floor level arranged on the side walls. Good ventilation can be obtained by arranging large windows at the gable ends. Sometimes forced ventilation is necessary in hot climates.

Fire Protection.—A complete system of hydrants should be fixed throughout the building, commanding the coal bunkers, and all parts of the structure. Regulation hose and nozzles can be fixed in cabinets at strategic points, readily accessible. Fire drill should be regularly undertaken so as to have the staff ready for emergencies. Buckets of sand must be placed in accessible positions on the switch galleries and cable tunnels or galleries.

Stepney Power House.—Fig. 8 is an illustration of the Stepney (London) Municipal power house built to the designs of Mr. W. C. P. Tapper. The cost of the buildings, which accommodate 6000 K.W. of steam plant, was only £2·85 per K.W. installed, and therefore exceptionally low. They consist of a steel skeleton, panelled with ferro-concrete, and built to the regulations of the London County Council. The engine-room and boiler house are particularly well lighted—the whole of the roofs, excepting the middle portion of the latter, being glazed with wire-netting glass. The temporary end is of corrugated iron-sheeting, covered inside with a preparation of cork dust so as to prevent sweating.

Coal is obtained from river barges by a simple arrangement of cranes and an overhead conveyor leading to the bunkers and returning through the ash gallery. The boilers are in two rows and are Babcock water tube, each with an evaporative capacity of 11,000 lbs. per hour. Future boilers will be rated at 22,000 lbs. per hour.

Each range of boilers has its separate steel chimney, one range fitted with chain-grate stokers being equipped with induced

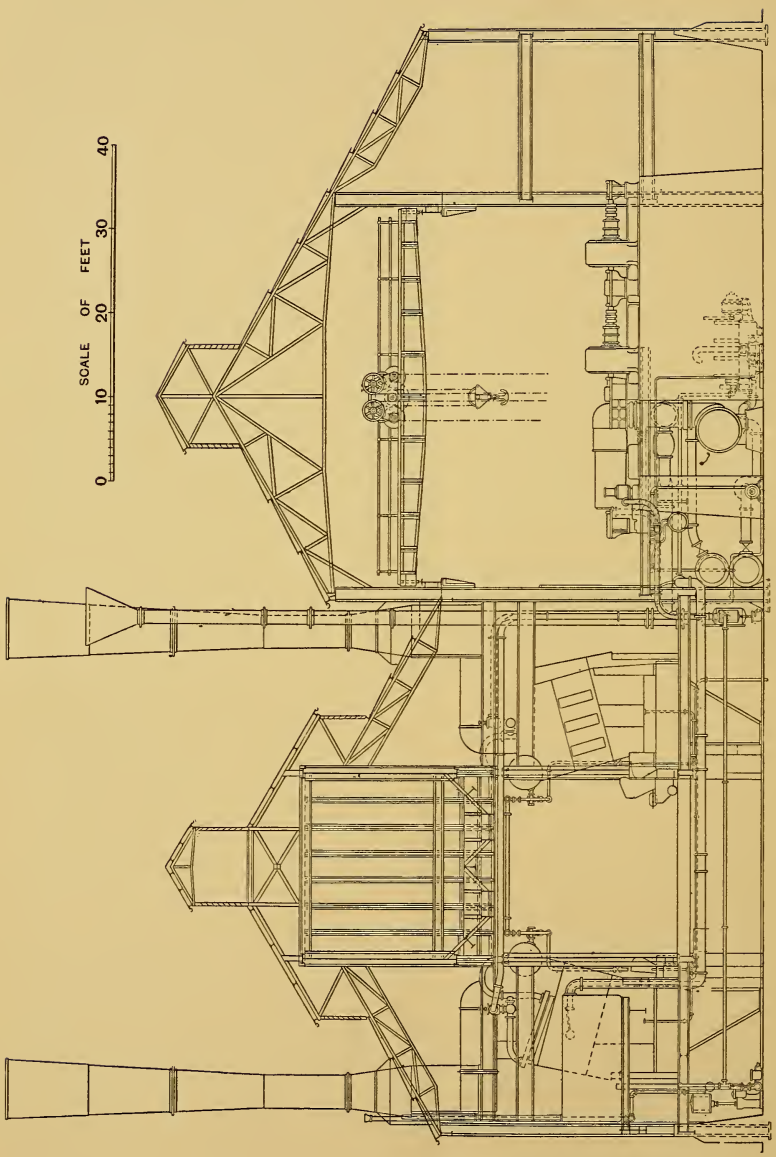


FIG. 8.

draught, and the other with underfeed stokers and forced draught. All the steam pipes are carried below the engine-room floor level. There are four 1000-K.W. turbo-generators, each consisting of a Parsons turbine driving two direct-current machines, with a total output of 4350 amperes at 230 volts. The generators are also fitted with slip rings, and will give an alternating output of 4130 amperes at 140 volts 3-phase 50-cycles, and are used in conjunction with step-up transformers. There is also one 2000-K.W. turbo-generator, with a rated output of 2350 K.V.A. at 6000 volts. The condensing plant consists of "contraflo" surface condensers, with electrically driven Edwards air pumps and Roturbo circulating pumps. The river water for circulating purposes is brought to the condensers in 3-foot pipes, and the pipes extend 150 feet into the river, and are so arranged that the direction of flow can be reversed from time to time so as to scour them of silt and other deposit.

Buenos Ayres.—The large power house at Buenos Ayres under construction by the German Transatlantic Company, which may be taken as typical of a modern power house of large size, shown in Fig. 5, is built of steel and concrete, and will eventually be equipped with plant of approximately 110,000 H.P. When completed it will contain ten 11,000-H.P. turbo-generators, running at 750 R.P.M., each capable of developing 14,200 H.P. for two hours. The boiler houses will be arranged in five bays, each containing twelve Babcock marine type boilers. Each boiler has a normal evaporation of 24,600 lbs. of water per hour, and with a maximum evaporation of 30,800 lbs., at a working pressure of 190 lbs. per square inch. The superheaters are provided to give a maximum additional temperature of 200° Fahr. There will be six chimneys. Ocean-going colliers are to discharge the coal alongside the power house wharf. The coaling plant will deliver the coal into storage silos or direct into the overhead bunkers, as shown in Fig. 5, first passing the coal through suitable breakers. Travelling bridges are to be constructed, each with tipping tray conveyors to handle large coal; 4½-ton tip cranes will be placed on these bridges, each with a working radius of 35 feet, and capable of hoisting the maximum load at a speed of 100 feet per minute, and handling 50 tons per hour. The tray conveyors will transport 100 tons per hour, and will deliver the coal into breakers placed in towers

at each end of the silos, so as to prepare the coal for use in the mechanical stokers. As the coal descends to the distributing conveyors it is automatically weighed and registered, when it is delivered through rotary fillers to either of two gravity bucket conveyors, which feed either into the silos or direct into the overhead bunkers; or from the silos to the bunkers, as may be required. Green's economisers are arranged on a floor above the boilers. The steam from each set of six boilers is taken to a 14-inch main at the rear end of the boilers, the two mains in each boiler house being connected by a cross-over pipe; the other ends of the steam mains passing across the pump-room into steam separators fixed in the engine-room basement, the separators being connected by a 14-inch main, so that any set of boilers can supply any turbine. The steam consumption of each turbine can be continuously measured, as the condenser air pump discharge is taken through Schilde water meters before it enters the hot well. The turbines are of the parallel flow type with two cylinders, one high and the other low pressure. The normal consumption guaranteed with 180 lbs. at the stop valve and with a total steam temperature of 572° Fahr., and with a rated output of 7500 K.W., is 13·9 lbs., with circulating water at 60° Fahr. The surface condenser has a cooling surface of 13,993 square feet (1·73 square foot per K.W., or 0·091 square foot per pound of steam condensed), and is guaranteed to condense 110,200 lbs. of steam per hour when supplied with circulating water at 60° Fahr., and to maintain a 95 per cent. vacuum or a 90 per cent. vacuum when supplied with cooling water at 70° Fahr. The 12,000-volt generators have an output of 3750 K.W. at 90 per cent. power factor, and are direct coupled in tandem to each turbine, one generator having a frequency of 25 cycles and the other 50 cycles. An exciter direct coupled to the generator shaft has an output of 110 K.W. at a pressure of 220 volts. The total weight of each set including its condenser is 475 tons. The alternators are cooled on Brown Boveri's ventilation system, cold air being admitted at both ends of the alternator through openings in the bed plate, the air being blown by means of fans fixed at the ends of the rotor through channels in the rotor field magnet wheels, and thence through the stator to an outlet on the top of the machine casing.

Bahia Blanca.—This power house contains at present seven Babcock boilers, each evaporating 23,000 lbs. per hour, with economisers, forced draught fans, and under-feed stokers; and five 1250-K.V.A. triple expansion steam alternators, 6600 volts, 3-phase, 50 ~ with Le Blanc surface condensers and pumps. The area occupied is 3·8 square feet per K.W., and the volume 228 cubic feet per K.W.; the capital cost of the building in English equivalent being £4·5 per K.W.

A liberal amount of room was given by the Author to the spacing of the plant on account of the high temperatures experienced in midsummer. The boilers are set back from the wall for some distance, as shown in Fig. 28, the space at their backs being occupied by the economisers, feed pumps, hot wells, and Venturi meters, and by the Lea recorder, as well as by the access gangways to the flues. At the front of the boilers Kinnear roll-top doors have been fixed, which may be kept open during very hot weather and closed in bad weather or during dust storms. The overhead bunkers are arranged to hold 1100 tons of coal, which represent one month's supply for the plant when working at the normal load factor of 30 per cent. Coal and ash handling plant is installed. In the engine-room, besides the five 1250 K.V.A. sets, there are two 75-K.W. steam-driven exciters. The surface condensers are housed in the open basement, as shown in the figure, and are directly accessible by the 30-ton overhead crane. The high-pressure switchboards are carried on three galleries, *i.e.* basement, engine-room, and first-floor levels.

Gas Power Houses.—The cost of buildings for a gas engine power house is approximately as follows: For a steel-framed structure with brickwork filling and slate roof complete with stanchions and walls, foundations and floors, floor tiling and inside glazed brick dado 6 feet high, covering an area of 103 × 250 feet, or 25,750 square feet, £13,000, or 10*s.* per square foot. The mean height was 43 feet, so that the volume was 1,106,250 cubic feet, and the price per cubic foot about 3*d.* This housed 10,500 K.W., and cost £1·24 per K.W., exclusive of engine foundations.

In the same class of building for a larger power house designed to accommodate 20,000 K.W., and covering an area of 260 × 250 feet, at the same mean height of 43 feet, the cost

was £24,000, representing a cost of 7*s.* 6*d.* per square foot, 2*d.* per cubic foot, and £1·2 per K.W. installed, again omitting engine foundations. It must be remembered when comparing this with steam-driven power houses, that there is no boiler house, and the area and volume required are only 3·25 square feet and 140 cubic feet respectively per K.W. installed, as compared with 4·7 square feet and 235 cubic feet respectively in ordinary large-sized steam turbine power houses. Plate IV. represents a section through the 20,000-H.P. gas station. Brickwork buildings to accommodate five 2000-K.W. gas-driven sets were also carefully estimated for. In this case there was no steelwork structure, the buildings being of brickwork throughout, the walls, of course, being of the normal thicknesses. The area covered was 300 × 206 feet, and the mean height 43 feet. The estimate was as follows :—

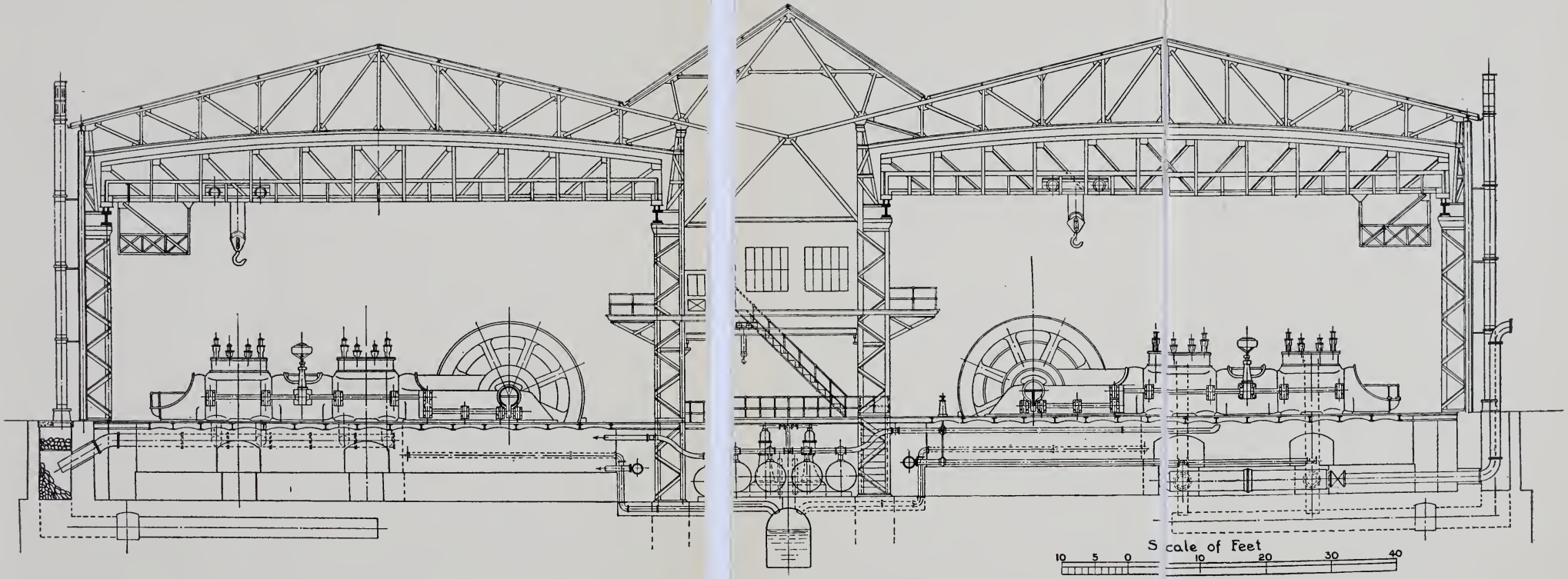
	£
Excavation	2500
3-inch concrete and foundations throughout	4875
Brickwork	3125
Roof principals	3300
Slating	900
Plumbing and other trades	500
Contingencies, etc.	1600
Total	£16,800

Representing a price of 5*s.* 5*d.* per square foot, 1½*d.* per cubic foot, and £1·68 per K.W. installed. This price is, however, certainly on the low side.

Small ***versus*** **Large Power Houses.**—The old policy of building small power houses has now given place to concentration of plant, involving the use of larger boiler units and larger steam generators, with a resultant less capital cost and more economical cost of production per unit of energy delivered.

The average cost of power house buildings in large cities is from £6 to £11 per K.W. installed; in smaller provincial towns from £3·5 to £6 per K.W., and for larger power houses outside cities from £2·5 to £3 per K.W. The price will obviously vary according to the country and the locality.

Generally speaking the cost of plain, substantial buildings may be reckoned for estimating purposes approximately as follows :—



Section.

PLATE IV.—20,0 00 H.P. GAS POWER HOUSE.

[*To face page* 42.

£5·00 per K.W.	. . . .	2500 K.W.	installed
£4·00 ,,	. . . . .	5000 ,,	,,
£3·25 ,,	. . . . .	10,000 ,,	,,
£2·75 ,,	. . . . .	25,000 ,,	,,
£2·50 ,,	. . . . .	50,000 ,,	,,
£2·33 ,,	. . . . .	100,000 ,,	,,

Cable Subways.—In certain power houses whence there are large numbers of cables radiating, it is sometimes necessary and

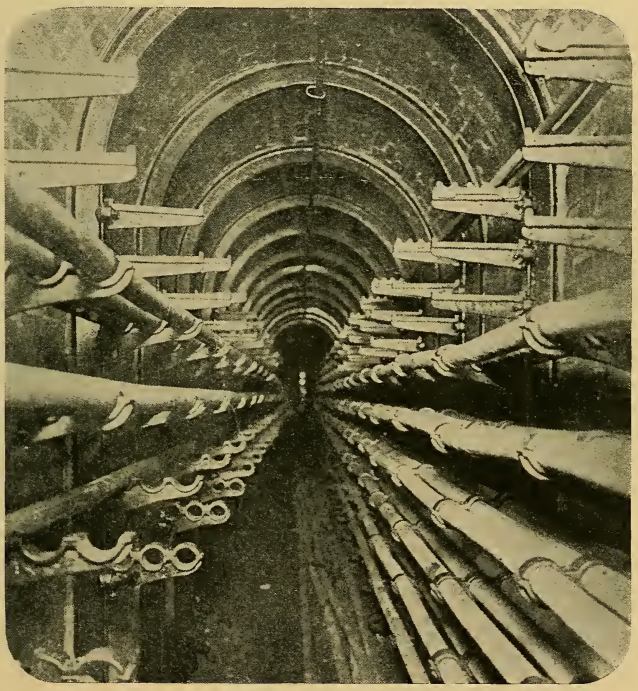


Fig. 9.

cheaper to build a subway, with side racks, as shown in Fig. 9. This subway is 940 yards long and 10 feet high by 5 feet wide, and built of 18-inch brickwork, with 4 feet of cover between the crown of the arch and the road surface. The approximate cost of the excavation brickwork complete, cable, racks, and reinstatement, was £27·3 per lineal yard.

Repair Workshops.—A repair workshop is necessary in a power

house equipment. This should be handy to the engine-room. The equipment shown in Plan (Fig. 10) may be taken as typical The following tools will usually suffice, viz. :—

(*a*) One 21-inch upright drilling machine, with four speeds, foot-operated striking gear, with three union chucks.

(*b*) One shaping machine.

(*c*) One suitable gap-bed self-acting lathe, hand-feed adjustment gear, micrometer adjustment to surfacing screw, complete with change wheels, chucks, hollow spindle, etc.

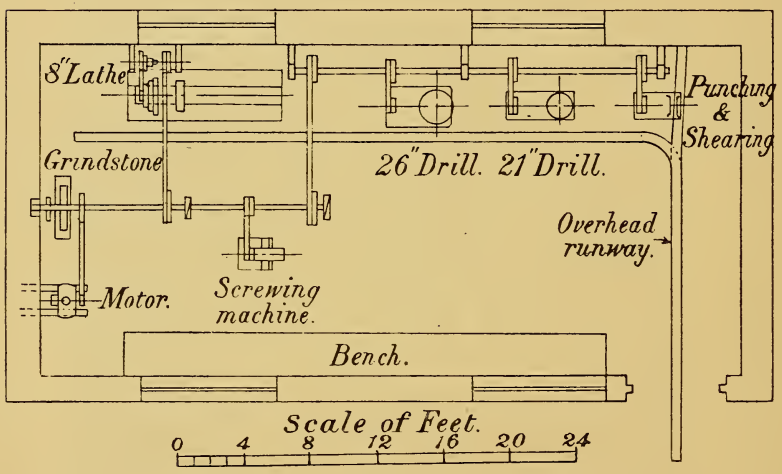


Fig. 10.

(*d*) Screwing machine with quick releasing dies.

(*e*) Six-inch gap lathe.

(*f*) Small brass-finisher's lathe.

(*g*) Bench disc grinder, fitted with steel emery wheel, and solid emery wheel, with table and other accessories.

(*h*) 36-inch by 8-inch grindstone, complete with details.

(*i*) Portable screwing machine, with disc to take up to, say, 4-inch pipes.

(*j*) 12-ton jacks with run-out of 12 inches.

(*k*) Ten-ton jacks as may be required.

(*l*) Double-purchase hoisting crabs to lift 5 or 3 tons are sometimes required in distant places.

(*m*) Self-sustaining 7½ tons pulley block, tested to 11 tons, with chains and some smaller blocks if necessary.

(*n*) Set of stocks and dies.

(*o*) Surfaceplate.

(*p*) Bench fitted with vices.

Spare Gear Room.—The buildings should contain a spare gear room, on the walls of which spare parts of all the plant can be hung, or the smaller parts arranged in shelves, as in an ordinary factory stores. By arranging these systematically a stock of spare parts can be more easily controlled, and thus spares kept ready to hand out when emergencies arise. Such parts as spare gauge glasses, valves of each kind, packing rings, turbine blades, piston rings, brasses, stator coils, brushes, insulators, instruments, and oil break switches, to mention only a few, are then always to hand. In remote situations it is well to construct a drying-room for high-tension coils, etc.

Oil should be kept in special tanks in an annexe to the main building, and such inflammable stores as waste and rags should be kept apart.

Other Offices.—The superintendent engineer's office should be arranged in a convenient position, so as to be easily accessible and comfortable, and not placed in a hot and ill-ventilated situation. Usually it is placed so as to give a commanding view of the engine-room. Telephonic communication (in a large plant) should be arranged between this office and the boiler houses, engine-room (at several points), and operating switchboard respectively. Separate mess-rooms, lavatories, and bath-rooms should be provided for the engine-room and boiler-house staff respectively.

Telephonic and Telegraphic Communication.—An arrangement of electrical signals should be arranged between the control switchboard and each engine, and indicators or telephones between the switchboard and the boiler houses. In some cases the speed of the steam sets is directly controlled from the switchboard gallery by means of reversible motor control.

Travelling Cranes.—These may be conveniently considered here as a part of the building equipment. In the engine-room a travelling crane should be provided of sufficient size to take the maximum load represented by the heaviest piece of machinery

required to be handled, such as the bed plate of an engine, or alternator frame, or condenser body. In large power houses, say above 5000 K.W., this should be motor driven, but in small power houses it is usually hand operated.

The main engine-room crane will command all the engine-room equipment including the condensing plant. Should the design of the power house be such that the condensers are housed in a separate bay, then a smaller hand-operated crane must also be fixed in that annexe.

A small travelling crane should also be provided in the workshop.

Single girder cranes require least head-room, and are useful in workshops, or over economisers and such like places where small weights are handled. The lifting gear travels in the bottom flange of the cross girder.

Hand-operated cranes in engine-rooms are usually of the double girder type, which will, of course, take heavier lifts and which allow the crab operating chains to be carried further away from the centre of the load, with a minimum head space and a capability of lifting as near as possible to the sides of the building.

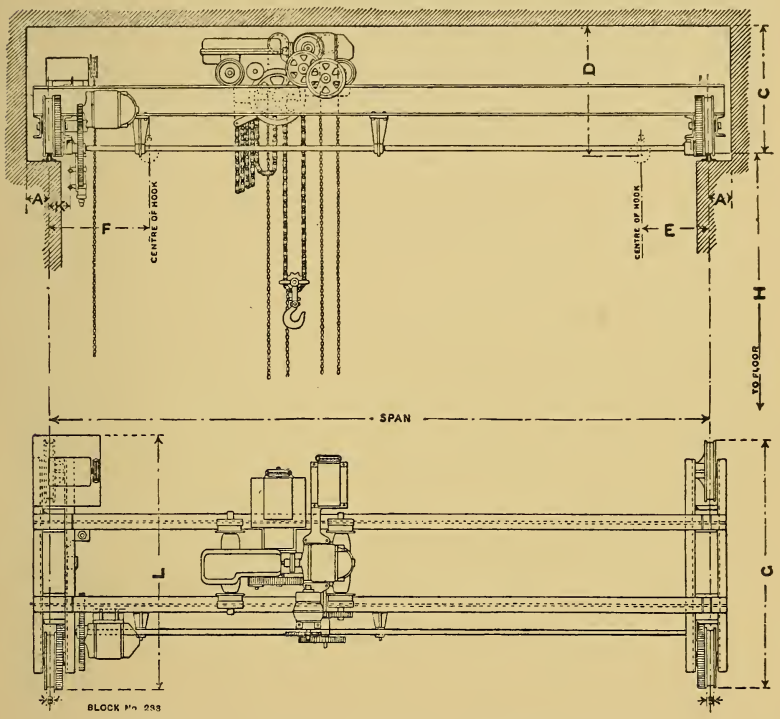
Electrically Operated Cranes.—For the larger power houses, electrically operated cranes are advisable. These can be arranged either (*a*) for electric lifting only, the cross traverse and main travel being hand operated; or (*b*) electric lifting and main travel, the cross traverse being hand operated; or (*c*) complete electrical equipment, operated either from a cage on the crane or from the floor. These are fitted with overwinding switches, so that the current is automatically cut off from the hoisting motor when the hook has risen to a predetermined height. Table XII. sets out the leading dimensions and speeds for standard electrically operated cranes.

When electrically operated cranes are adopted, the motors may be driven either from a low-tension 3-phase supply or from the auxiliary exciter direct current sets whichever may be found more convenient. Some designers prefer to drive all the station auxiliary motors from the 3-phase main supply through step-down transformers, others prefer to keep these motors more independent of the main supply by driving them from the exciter

circuit. Preference should, however, in the Author's opinion, be given to the former method.

Cranes are always proof tested to 50 per cent. excess full load.

TABLE XII.



ELECTRIC OVERHEAD TRAVELLING CRANES.—SPEEDS.

Power of crane.	Hoist speeds.				Speed of cross traverse.		Speed of main travel.	
	1st Range.		2nd Range.					
	With full load.	No load.	With full load.	No load.	With full load.	No load.	With full load.	No load.
Tons.								
1¼	18	36	30	60	80	110	180	200
2½	12	24	20	40	65	110	160	185
5	9	18	15	30	65	110	135	175
7½	9	18	15	30	65	110	135	180
10	8	16	12⅔	25	65	110	135	190
15	5	10	8⅓	16½	65	110	120	190
20	4	8	6¼	12½	65	110	120	190

Dimensions.							Table of Dimension C.							
Power of crane.	A	D	E	F	G	L	10 ft. span.	15 ft. span.	20 ft. span.	25 ft. span.	30 ft. span.	35 ft. span.	40 ft. span.	45 ft. span.	50 ft. span.
Tons.	in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
1¼	7	3 9	2 6	2 4	5 5	5 9	4 4	4 4	4 4	4 6	4 8	4 11	4 11	5 1	5 2
2½	7½	4 2	2 2	2 7	6 9	6 9	4 5	4 5	4 6	4 8	4 8	5 0	5 2	5 2	5 1
5	7½	4 11	2 6	2 11	6 9	6 9	4 8	4 9	4 11	5 2	5 3	5 5	5 6	5 4	5 6
7½	8½	5 11	2 7	3 4	8 7	8 7	5 4	5 6	5 9	5 10	6 0	6 1	6 4	6 1	6 1
10	8½	6 0	2 8	3 5	8 7	8 7	5 5	5 7	5 9	6 0	6 1	6 2	6 4	6 2	6 3
15	9	6 9	2 11	4 0	11 6	11 6	6 2	6 5	6 6	6 8	6 11	6 11	7 1	7 1	7 1
20	9½	7 6	3 2	4 6	11 6	11 6	6 7	6 11	7 1	7 3	7 5	7 7	7 7	7 6	7 8

Approximate Weights.

Span in feet.	10	15	20	25	30	35	40	45	50
Load.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.
1¼ tons . . .	42	44	46¼	51	56½	64	84¾	103	108¼
2½ ,, . . .	48½	50¾	55	60	67¼	85¾	103	117¼	148¾
5 ,, . . .	56	59¾	64½	72	87½	103¼	116¾	146	144¾
7½ ,, . . .									
10 ,, . . .	81¼	87¾	96	113¼	125¼	138¾	160½	171¾	190
15 ,, . . .	101	107¼	119	132¼	158¾	169¼	186½	212¼	225
20 ,, . . .	133¼	143¾	154¾	170¾	189½	217¾	230		

Approximate Weights of Heaviest Single Piece.

Span in feet.	10	15	20	25	30	35	40	45	50
Load.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.	cwts.
1¼ tons . . .	23¾	23¾	23¾	23¾	23¾	23¾	*25½	*35	*37
2½ ,, . . .	25¼	25¼	25¼	25¼	25¼	25¼	*31¼	*38¼	*53¾
5 ,, . . .	32½	32½	32½	32½	32½	32½	*35¼	*49½	*49
7½ ,, . . .									
10 ,, . . .	48½	48½	48½	48½	48½	48½	48½	*53	*60¾
15 ,, . . .	57¼	57¼	57¼	57¼	57¼	57¼	57¼	*62¼	*68½
20 ,, . . .	82¾	82¾	82¾	82¾	82¾	82¾	82¾	—	—

Where marked * the heaviest piece is one of the cross girders. In all other instances the heaviest piece is the case which contains the lifting gear (travelling crab) and other sundries.

Costs of Overhead Travelling Cranes.—The cost of cranes is approximately as follows:—

Hand-operated 10-ton . . . . £8 per foot main span.
Ditto 30-ton . . . . £10 ,, ,,
Electrically operated 30-ton . . . . £20 ,, ,,

Brick Chimneys.—These are dealt with under this section in preference to that on steam-raising plant (Chap. IV.) since large brick chimneys may be deemed an integral part of a building and properly a part of an architect's work.

Mention is made of brick chimneys since they are usually necessary in intra-mural power houses. Outside power houses are now more usually equipped with short steel stacks and forced or induced draught, particulars of which are given in Chap. IV.

For the internal areas and heights with various sizes of boiler plant, reference may be made to the subsequent table (XXV.) given in the chapter on Steam-raising Plant.

Chimneys must be erected on firm foundations so as to prevent unequal settlement. The inside surfaces should be smooth so as to reduce the resistance to the flow of gases. Fig. 11 shows a typical brick chimney constructed to the Author's design. The principal dimensions of this shaft are 132 feet high × 50 square feet sectional area at cap. The chimney is hexagonal on a square plinth. It is customary to specify that in building such a shaft the brickwork shall be carried up regularly, but that when the work has reached ground level an interval of one week is to elapse before the work is proceeded with, and similar rests after the first 50 feet of brickwork and each subsequent 25 feet have been built up. Ventilating bricks, usually 14 × 10 inches, are built in the outer walls, with openings connecting the space between the firebrick lining and outer walls, so as to average the temperature and to prevent undue expansion on the stock brickwork. The firebrick lining is usually carried up for a height of 40 or 50 feet.

The batter varies from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch per foot on each side. For small shafts the thickness of brickwork is 9 inches, or one brick downwards for 25 feet from the cap, increasing a half a brick or $4\frac{1}{2}$ inches for each further 25 feet downwards. For large chimney shafts, *i.e.* those exceeding 5 feet in internal diameter the top 25-foot section should be $1\frac{1}{2}$ bricks or 14 inches thick, increasing a half a brick downwards in 25-foot sections as before. A heavy stone cap is always fixed so as to consolidate and bind the structure and also to act as a weather guard. The cut stones forming the cap are fitted accurately and further secured by strong steel dowels cemented and sealed into the recesses of the stonework.

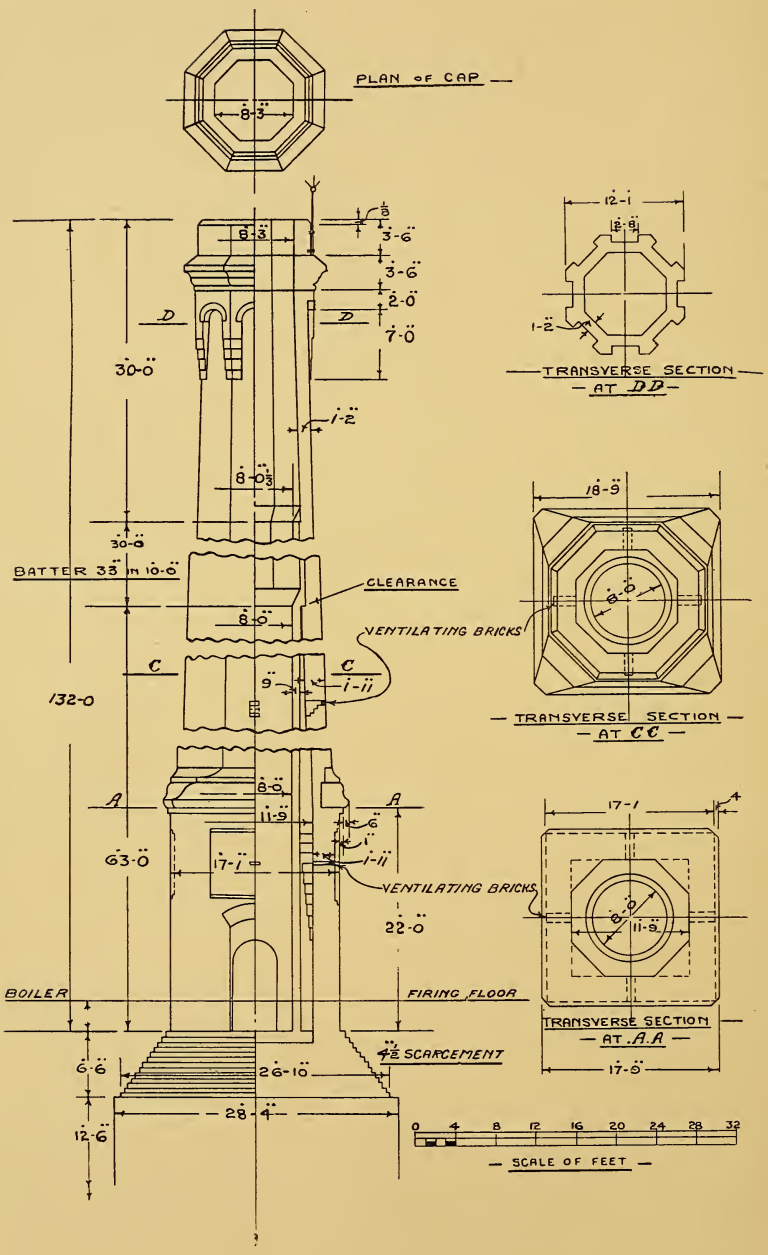

PLAN OF CAP
8-3
12-1
8-9
1-2
TRANSVERSE SECTION
AT DD
3-6
3-6
2-0
7-0
D
D
30-0
1-2
8-0 3/4
30-8
BATTER 33 in 10-0
CLEARANCE
8-0
VENTILATING BRICKS
C
C
9
1-11
132-0
18-9
8-0
TRANSVERSE SECTION
AT CC
A
A
8-0
11-9
6
1
1-11
63-0
17-1
VENTILATING BRICKS
22-0
17-1
8-0
8-0
11-9
BOILER
FIRING FLOOR
TRANSVERSE SECTION
AT A.A
4½ SCARCEMENT
6-6
26-10
17-0
28-4
12-6
0 4 8 12 16 20 24 28 32
SCALE OF FEET

FIG. 11.

Elaborate and costly shafts for power houses are becoming rarer, and it is much better practice wherever possible to adopt a smaller shaft with artificial draught. The following table (XIII.) gives the general dimensions for various brick chimneys :—

TABLE XIII.

Height of shaft above grate level.	Approximate power natural draught.	Internal dimensions.				Thickness of walls.		Area ratio.
Feet.	External air, 68° F. ; heated column, 600° F.	Base at ground level.		Diameter at cap.		Ground level.	Cap.	
	inches of water.	ft.	ins.	ft.	ins.	inches.	inches.	
100	0·70	4	8	3	0	28	9	2·4
120	0·84	5	6	3	6	28	9	2·4
160	1·12	9	0	5	0	36	14	3·24
180	1·26	6	4	4	6	54	14	2·00
200	1·40	5	3	3	6	36	14	2·28
225	1·575	16	0	6	6	36	14	4·00
250	1·75	19	0	13	0	40	14	2·13

Weight of Brick Chimneys.—The weight of brick shafts may be found approximately from the following formula (Hutton) :—

$$W = \frac{H2 \times b}{B} \times P$$

where W = total weight of shaft,
H = height,
B = external dimension of shaft at base,
b = mean external width of shaft,
P = maximum wind pressure, say, 60 lbs. per sq. ft.

As the weight of built brickwork averages 112 lbs. per cubic foot, the mean thickness of such a chimney in feet, if square, would be

$$\frac{W}{H \times 6 \times 448}$$

If hexagonal, multiply result by 0·75
If octagonal, ,, ,, ,, 0·65
If circular, ,, ,, ,, 0·55

Area of Chimneys.—The internal area at cap of any shaft can be found from the following formula:—

$$A = \frac{W \times G \times C}{\sqrt{H}}$$

where A = internal area at cap in square feet,
W = pounds of fuel consumed per square foot of grate per hour,
G = total grate area in square feet,
H = height of shaft above grate level,
C = multiplier for various ranges of boilers; the values of C being 1 for one boiler, 0·85 for a battery of 2–6 boilers, 0·75 for a battery of 7–12 boilers.

From the above formula the size of any shaft can be determined, taking care to give the highest probable value to W which is likely to occur in practice.

The cap stones of large shafts are usually arranged as shown in Fig. 11, each stone being bedded and set in cement mortar, and secured to its adjacent stones by copper dovetailed dowells some $9 \times 4 \times 1$ inches sunk into the stones and sealed in with lead. The vertical joints of the capping are arranged so as to break joint with the next course.

CHAPTER IV

STEAM-RAISING PLANT

Boilers.—The selection of the type and size of boilers must depend largely on the size of turbines or engines, space available, and on the geographical position of the particular power house.

The two available types are, of course, the water tube and the drum or fire tube, and since the latter is much restricted both in pressure and in output, it can only be adopted for small installations, thus leaving the water tube as the only available type for larger units, as its steam-raising power per unit of area and volume is several times that of the drum type. For export work and positions where minimum weights for transport are necessary, then, a sectional water-tube boiler is indispensable. The drum type may be used with good efficiency for small units in conjunction with a liberal size of economiser, and especially in the case of certain lower load factors on account of the large storage capacity both of water and of steam.

Drum boilers are generally of the Lancashire two-furnace type, with or without cross circulating tubes, or of the special "Galloway" type, or of the so-called "dry back marine" type. Water-tube boilers are either of the semi-horizontal type, *e.g.* the Babcock and Wilcox, where the tubes are inclined at an angle of 15° from the horizontal; or of the vertical type, *e.g.* Stirling, where the tubes are more or less vertical. Water-tube boilers may also have straight tubes, as in the former type, or bent tubes, as in the latter. This is not a treatise on boilers and their construction, so the designer must be left to make his choice of the specific type for his requirements, and the question here is a broader one of principle rather than details of any particular plant. The designer must fully weigh the pros and cons in each particular instance. Broadly

speaking, the Author thinks there is much to be said in favour of the straight-tube sectional boiler in the way of inspection, cleaning and renewal of tubes, always provided the particular type allows free circulation and high thermal efficiency. Certain data are necessary to determine the best type of boiler for specific cases; these are—

Choice of Type.—(1) Size of steam engine or turbine and steam consumption per I.H.P. per hour.

(2) Quality of feed water, or "make up" feed water, available.

(3) Qualities of fuel available and the commercially cheapest kind to be used.

(4) Estimated daily average load factor of power house.

(5) Available site, and accessibility for transport of materials.

Taking these points in order:

The following Table, No. XIV., gives the approximate output per boiler in K.W. and in H.P. and limit size of each well-known class, both for condensing plant, as is more usual, and also for non-condensing; the steam consumption of the turbine or engine being taken at normal figures, obtainable with any high-class plant.

TABLE XIV.

	Turbines (condensing). H.P.	Reciprocating engines.		Space occupied. (Turbine rating.)	
		(Condensing.) H.P.	(Non-condensing.) H.P.	Per K.W.	Per H.P.
				sq. ft.	sq. ft.
Water-tube .	2680	2000	—	0·22	0·17
Dryback marine	715	625	500	0·70	0·56
Lancashire .	715	625	500	0·85	0·68

This table (as well as Table No. XV.) shows that there is a distinct limit to the adoption of drum-type boilers, and that in cases of plant exceeding 1000 K.W. output for each unit of plant they become prohibitive on account of the space occupied and the increased cost of buildings and pipe work and attendance.

The dry-back marine type requires about 34 square feet of floor space, and costs about £100 per 1000 lbs. evaporated per hour at normal rating. The Lancashire type requires about 37 square feet floor space, and costs about £100 (with requisite economiser) per 1000 lbs. evaporated per hour at normal rating. The

water-tube boiler requires 18 square feet of floor space, and costs about £75 per 1000 lbs. evaporated per hour at normal rating: or £102 complete with super-heater and mechanical stokers.

Drum Type Boiler.—As simplicity of design is eminently necessary to obtain good results, with as short and direct a pipe range as possible, obviously the best lay-out is obtained in arranging one boiler to each engine, as shown in Fig. 1, *ante*.

There a drum type (Lancashire) 30′ × 8′ 6″ boiler is shown supplying a 500-K.W. reciprocating engine and generator. The boilers are spaced 11 feet 6 inches apart, which is also a convenient spacing for this type of engine.

In Fig. 12, a 1000-K.W. reciprocating engine is shown. This size requires two boilers per engine. It is at once seen that with the drum boilers arranged in a continuous battery the space between the engines is wasteful, involving an unnecessary amount of room and cost of buildings. The same criticism would apply were the boilers arranged in two rows with the firing floor between them. While the engine-room would be reduced, the boiler house would be increased in area.

The following Table, No. XV., sets out the standard sizes of Lancashire type boilers:—

TABLE XV.

STANDARD LANCASHIRE BOILERS.

Size of boiler.		Weight of boiler at the following pressures.		Weight of boiler.	Heating surface.	Grate area.	Chimney height.	Coal.		Total steam per hour.
Height.	Diameter.	120 lbs.	180 lbs.	Fittings.				Burnt per sq. foot of grate area.	Total per hour.	
ft.	ft.	tons.	tons.	tons.	sq. ft.	sq. ft.	ft.			lbs.
22	6·5	11·25	15·0	3·0	570	25	100	20	500	4000
24	6·5	12·0	15·75	3·0	620	27·5	100	20	550	4400
24	7·0	14·0	18·0	3·5	680	29·75	120	24	700	5600
26	7·0	14·75	19·0	3·5	740	32	120	24	770	6160
28	7·0	15·75	20·0	—	800	32	130	25	800	6400
30	7·0	16·75	21·0	—	860	32	140	26	830	6640
28	7·5	16·5	22·0	4·0	870	35	150	28	980	7840
30	7·5	17·75	23·0	4·0	930	35	165	30	1050	8400
30	8·0	20·25	27·0	—	1000	38	180	32	1220	9760
30	8·5	23·0	30·0	4·5	1050	40	185	33	1320	10,560
30	9·0	25·0	34·0	4·5	1120	43	200	35	1500	12,000

NOTE.—The above evaporative capacities are for a good quality of coal (of about 13,500 to 14,000 B.Th.U.), and assuming the boiler to be fitted with economisers of adequate and properly proportional heating surface.

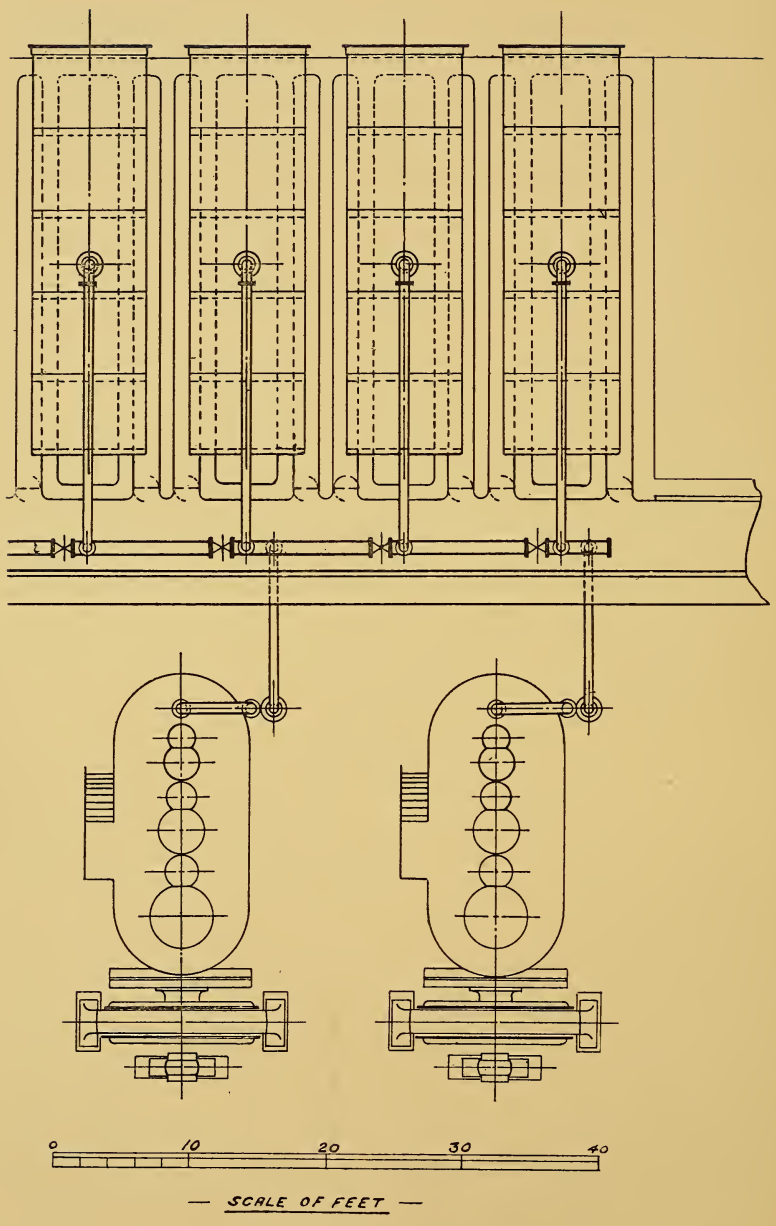


Fig. 12.

The Galloway boiler has about 10 per cent. more heating surface than the plain Lancashire type as above, with consequent higher efficiency and higher evaporative capacity than the figures given in the table (No. XV.).

Or consider next the dryback marine type, which is doing excellent work in many smaller stations. This type, having larger heating surface per unit volume of drum, has a consequent higher evaporative duty and a larger H.P. per square foot of space occupied. This type, too, is less unwieldy than the larger plain drum type. Owing to their greater diameter, shorter drums, and higher duty, they are available for simple designs, with larger units of plant than the plain drum type, and they can be better laid out in double rows. Quite a neat lay-out can be made for moderate-sized power houses, as is shown in Fig. 13.

Both classes of drum boiler possess the great disadvantage of difficulty of transport owing to the large dimensions of the drums and their total weights. Again, under emergency, neither class can be forced without running the risk of damage to furnaces or tube plates, and of incomplete and wasteful combustion. With boilers of this construction, working at normal rates of evaporation, an economiser must be added, and is essential if the heat contained in the fuel is to be properly utilized.

In all larger power houses water-tube boilers are obligatory. In fact, for plant units of 1000 K.W. and upwards the water-tube class is indispensable, having regard to economy of space and good design. The water-tube type, moreover, is safer than the drum, and is used for the now more prevalent higher pressures. Steam can be raised more rapidly, the boiler can be forced to a high degree of overload, though certain types are given to priming if overloaded too greatly. It is made sectionally, none of the individual parts are heavy or too bulky, and it can therefore be easily transported either by land or sea. The lay-out of water-tube boilers with the larger units of prime movers is shown in Figs. 2 and 4, *ante*.

Straight Water-tube Boilers.—Without unfairness to other makers, it may be said that the Babcock and Wilcox typifies the straight-tube type and is best known. This boiler is especially designed for easy transport *per mare et terram* and for easy erection. The one disability it possesses is the large number of

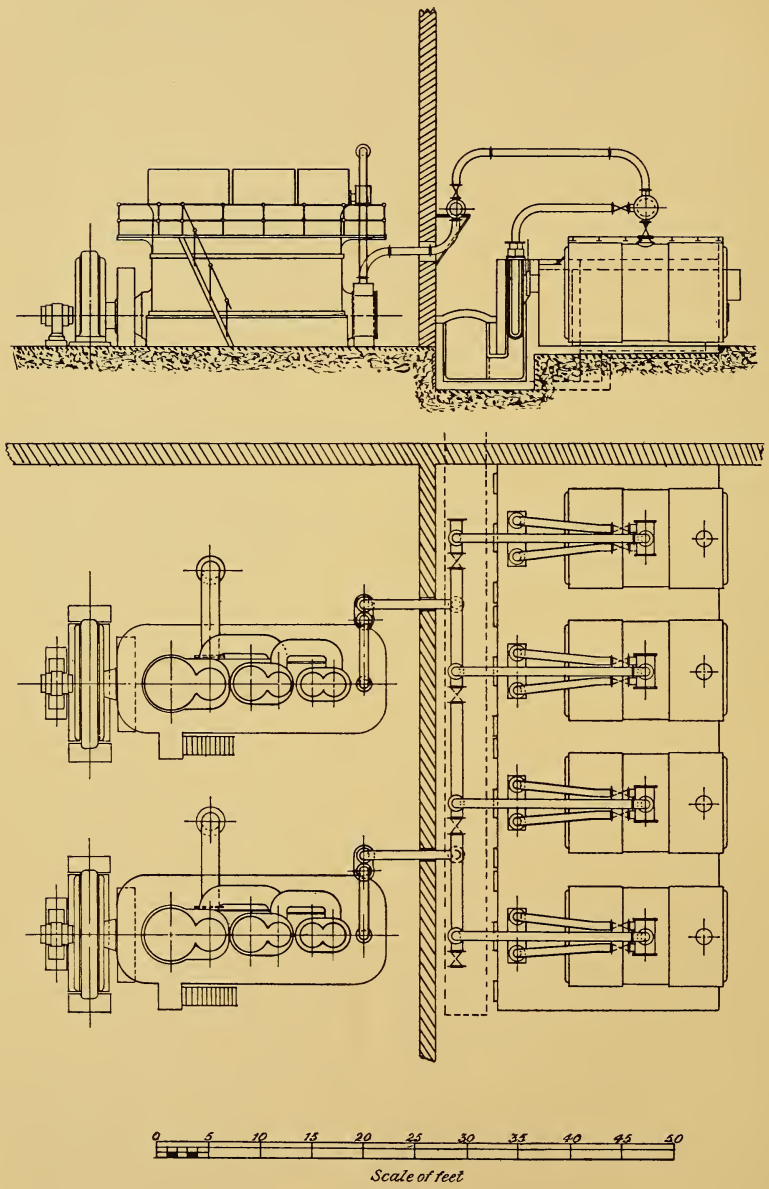


FIG. 13.

TABLE XVI.

Standard Sizes of Babcock and Wilcox Boilers.

W.I.F. Types.

Heating surface.	Evaporation per hour from and at 212° F.	Construction.						Furnace.		Tons.	Space occupied.				
		Tubes.			Drum.						Single boiler.				Two boilers in battery.
											Over brick-work.			Height when hand-fired.	
Sq. ft.		Wide.	High.	Long.	No.	Diam.	Long.	Width	Length.		Length.		Width.		Width.
				ft. in.			ft. in.	ft. in.	ft. in.		ft. in.		ft. in.		ft. in.
119	450	3	4	6	1	24	10 5	2	1×2 6	$3\frac{1}{2}$	9	6× 4	5× 9	$11\frac{1}{8}$	8 0
150	570	3	4	8	1	24	12 6	2	1×3 0	4	11	6× 4	5× 9	$11\frac{1}{8}$	8 0
181	680	3	5	8	1	24	12 6	2	1×3 6	$4\frac{1}{2}$	11	6× 4	5×10	$5\frac{1}{8}$	8 0
219	830	3	5	10	1	24	14 9	2	1×4 0	$4\frac{3}{4}$	13	6× 4	5×10	$5\frac{1}{8}$	8 0
293	1100	4	5	10	1	30	15 0	2	8×4 0	$5\frac{1}{2}$	13	6× 5	0×10	$11\frac{1}{8}$	9 2
343	1300	4	5	12	1	30	17 0	2	8×4 0	$5\frac{3}{4}$	15	6× 5	0×10	$11\frac{1}{8}$	9 2
401	1525	4	6	12	1	30	17 7	2	8×4 6	6	16	0× 5	8×12	$5\frac{5}{8}$	9 10
460	1750	4	6	14	1	30	19 9	2	8×5 0	$6\frac{1}{2}$	19	0× 5	8×12	$5\frac{5}{8}$	9 10
526	2000	4	7	14	1	30	19 9	2	8×5 0	7	19	0× 5	8×12	$11\frac{5}{8}$	9 10
593	2250	4	8	14	1	30	19 9	2	8×5 0	$7\frac{1}{4}$	19	0× 5	8×13	$5\frac{5}{8}$	9 10
735	2800	5	8	14	1	36	19 10	3	3×5 0	$8\frac{1}{2}$	19	0× 6	3×13	$11\frac{5}{8}$	11 0
870	3300	6	7	16	1	36	21 11	3	10×5 0	$10\frac{1}{4}$	21	0× 6	10×13	$5\frac{5}{8}$	12 2
983	3700	6	8	16	1	36	21 11	3	10×5 0	$10\frac{3}{4}$	21	0× 6	10×14	$0\frac{7}{8}$	12 2
1098	4200	6	9	16	1	36	21 11	3	10×6 0	$11\frac{1}{2}$	21	0× 6	10×14	$6\frac{7}{8}$	12 2
1218	4600	6	9	18	1	36	23 10	3	10×6 0	$12\frac{1}{4}$	23	0× 6	10×15	$0\frac{7}{8}$	12 2
1265	4800	7	8	18	1	36	23 10	4	5×6 0	$13\frac{1}{4}$	23	0× 7	5×14	$6\frac{7}{8}$	13 4
1411	5300	7	9	18	1	36	23 10	4	5×6 0	14	23	0× 7	5×15	$0\frac{7}{8}$	13 4
1426	5400	7	9	18	1	42	24 1	4	5×6 0	$14\frac{1}{4}$	23	0× 7	5×15	7	13 4
1619	6100	8	9	18	1	42	24 1	5	0×6 0	$14\frac{3}{4}$	23	0× 8	0×15	$7\frac{3}{8}$	14 6
*1741	6600	12	7	16	2	36	21 11	7	4×5 0	$17\frac{1}{4}$	21	0×10	4×15	$0\frac{7}{8}$	19 2
1790	6700	8	10	18	1	42	24 1	5	0×7 0	$16\frac{1}{4}$	23	0× 8	0×16	$1\frac{3}{8}$	14 6
1827	6900	9	9	18	1	48	24 3	5	7×6 0	17	23	0× 8	7×16	$1\frac{3}{4}$	15 8
*1966	7400	12	8	16	2	36	21 11	7	4×5 0	19	21	0×10	4×15	$6\frac{7}{8}$	19 2
2010	7600	9	10	18	1	48	24 3	5	7×7 0	$19\frac{1}{4}$	23	0× 8	7×16	$7\frac{3}{8}$	15 8
*2197	8300	12	9	16	2	36	21 11	7	4×6 0	$20\frac{1}{4}$	21	0×10	4×16	$0\frac{7}{8}$	19 2
2255	8500	10	10	18	1	54	24 5	6	2×6 6	$20\frac{3}{4}$	23	0× 9	2×17	$3\frac{3}{8}$	16 10
*2437	9200	12	9	18	2	36	23 10	7	4×6 0	22	23	0×10	4×16	$2\frac{3}{8}$	19 2
*2531	9500	14	8	18	2	36	23 10	8	6×6 0	$24\frac{1}{2}$	23	0×11	6×15	$8\frac{1}{4}$	21 6
*2690	10100	12	10	18	2	36	23 10	7	4×7 0	$24\frac{3}{4}$	23	0×10	4×16	$8\frac{1}{4}$	19 2
*2823	10600	14	9	18	2	36	23 10	8	6×6 0	$25\frac{1}{4}$	23	0×11	6×16	$2\frac{3}{8}$	21 6
*2852	10700	14	9	18	2	42	24 1	8	6×6 0	$25\frac{3}{4}$	23	0×11	6×16	$8\frac{1}{4}$	21 6
*3140	11800	14	10	18	2	42	24 1	8	6×7 0	$26\frac{3}{4}$	23	0×11	6×17	$2\frac{1}{4}$	21 6
*3240	12200	16	9	18	2	42	24 1	9	8×6 0	$27\frac{1}{4}$	23	0×12	8×16	$8\frac{1}{4}$	23 10
*3580	13500	16	10	18	2	42	24 1	9	8×7 0	$28\frac{1}{2}$	23	0×12	8×17	$2\frac{1}{4}$	23 10
*3654	13700	18	9	18	2	48	24 3	10	10×6 0	32	23	0×13	10×17	$2\frac{3}{4}$	26 2
*4020	15100	18	10	18	2	48	24 3	10	10×7 0	34	23	0×13	10×17	$8\frac{3}{4}$	26 2
*4510	17000	20	10	18	2	54	24 5	12	0×6 6	39	23	0×15	0×18	$2\frac{5}{8}$	28 6
*4780	18000	18	12	18	2	48	24 3	Stokers	96°	$54\frac{3}{4}$	23	0×13	10×18	$8\frac{3}{4}$	26 2
*5540	20800	18	14	18	2	48	24 9	,,	108°	$61\frac{1}{2}$	23	6×13	10×19	$8\frac{3}{4}$	26 2
*6182	23200	20	14	18	2	54	25 0	,,	120°	$67\frac{1}{2}$	23	6×15	0×20	$2\frac{7}{8}$	28 6
*7322	27500	24	14	18	3	42	24 9	,,	144°	$81\frac{1}{4}$	23	6×17	4×19	$8\frac{3}{4}$	33 2
8283	31000	27	14	18	3	48	24 9	,,	168°	100	23	6×19	1×20	$2\frac{7}{8}$	36 8

* These boilers have two steam and water drums, which are joined by a wrought steel cross pipe.

caps required to close the tubes, which require to be removed occasionally for inspection of tubes and for internal cleaning. On the other hand, by removing these caps, the water tubes may be easily inspected by placing a lamp at one end, and also easily cleaned. The ends of the tubes are expanded by a special taper mandril into the pressed steel header, and thus can also be easily cut and replaced. In this respect this boiler enjoys an advantage possessed by no other type. Accumulations of soot on the exterior of the tubes may be removed by steam hose and jet, for which access is given by small hand-holes built into the side walls of the brickwork setting, or by scrapers, for which access to the tubes must be provided. The latter method is better, and prevents corrosion of the tubes which may arise from the steam jet and accumulated soot.

There are other straight-tube types which have given excellent results, such as that made by Messrs. Clarke, Chapman & Co. of Gateshead, England. These tubes are expanded into specially shaped projections pressed out of the drum plates, with access doors placed immediately above each nest of tubes to permit of easy inspection, cleaning, and replacement (see Appendix I.).

Bent Water-tube Boilers.—The Stirling boiler typifies the bent tube class of water-tube boiler, and this boiler is frequently adopted for power houses. It possesses an advantage over the Babcock type in that the drums are smaller and can be more readily transported to situations up-country which are often difficult of access. It is claimed that, owing to the design of the boiler, and the more vertical inclination of the tubes, freer ebullition is obtained; the steaming is easier, and, owing to the curvature of the tubes, there are less strains on the boiler parts. It is also claimed that less scale can form or lodge in the tubes. On the other hand, good make-up feed water free from scale-forming matter is imperative. Owing to the curvature of the tubes and their smaller diameter they cannot be so easily inspected as the straight types, and there are more tubes for a given heating surface. There are, however, no caps to be ground in, nor special headers required into which the tubes have to be expanded. There are many other types of bent-tube boilers, for each of which special advantages are claimed in respect of details.

The following Table, No. XVII., gives the principal dimensions and particulars of weights, etc., of standard sizes:—

TABLE XVII.

STANDARD SIZES OF STIRLING WATER-TUBE BOILERS.

Heating surface.	Evaporation per hour from and at 212° Fahr.	Construction.							Width over brickwork.	
		Length over ends.			Main tubes.			Furnace. Length and width.	Single.	Battery.
		Of steam drums. Single.	Of steam drums. Battery.	Of mud drum.	Wide.	Deep.	Total.			
sq. ft.	lbs.	ft. in.	ft. in.	ft. in.				ft. in. ft. in.	ft. in.	ft. in.
212	800	5 7	4 8	3 9	4	8	32	3 6× 2 0	4 4	8 4
261	980	6 1	5 2	4 3	5	8	40	3 6× 2 6	4 10	9 4
310	1170	6 7	5 8	4 9	6	8	48	3 6× 3 0	5 4	10 4
406	1530	6 7	5 8	4 9	6	8	48	4 0× 3 0	5 4	10 4
539	2030	6 7	5 8	4 9	6	11	66	4 8× 3 0	5 4	10 4
624	2340	7 1	6 2	5 3	7	11	77	4 8× 3 6	5 10	11 4
719	2700	7 3	6 0	4 9	6	11	66	5 6× 3 0	6 0	11 0
795	2990	8 1	7 2	6 3	9	11	99	4 8× 4 6	6 10	13 4
949	3560	8 3	7 0	5 9	8	11	88	5 6× 4 0	7 0	13 0
1064	3990	8 9	7 6	6 3	9	11	99	5 6× 4 6	7 6	14 0
1081	4060	7 8½	6 5½	4 9	6	17	102	7 0× 3 0	6 0	11 3
1200	4500	8 2½	6 11½	5 3	7	16	112	7 0× 3 6	6 6	12 3
1255	4710	8 2½	6 11½	5 3	7	17	119	7 0× 3 6	6 6	12 3
1295	4860	9 9	8 6	7 3	11	11	121	5 6× 5 6	8 6	16 0
1311	4920	8 2½	6 11½	5 3	7	18	126	7 6× 3 6	6 6	12 3
1410	5290	10 3	9 0	7 9	12	11	132	5 6× 6 0	9 0	17 0
1525	5720	10 9	9 6	8 3	13	11	143	5 6× 6 6	9 6	18 0
1602	6010	9 2½	7 11½	6 3	9	17	153	7 0× 4 6	7 6	14 3
1776	6660	9 8½	8 5½	6 9	10	17	170	7 0× 5 0	8 0	15 3
1857	6970	9 8½	8 5½	6 9	10	18	180	7 6× 5 0	8 0	15 3
1949	7310	10 2½	8 11½	7 3	11	17	187	7 0× 5 6	8 6	16 3
2038	7650	10 2½	8 11½	7 3	11	18	198	7 6× 5 6	8 6	16 3
2197	8240	11 2½	9 11½	8 3	13	16	208	7 0× 6 6	9 6	18 3
2402	9010	11 2½	9 11½	8 3	13	18	234	7 6× 6 6	9 6	18 3
2529	9490	12 2½	10 11½	9 3	15	16	240	7 0× 7 6	10 6	20 3
2644	9920	12 2½	10 11½	9 3	15	17	255	7 0× 7 6	10 6	20 3
2861	10730	13 2½	11 11½	10 3	17	16	272	7 0× 8 6	11 6	22 3
3129	11740	13 2½	11 11½	10 3	17	18	306	7 6× 8 6	11 6	22 3
3234	12130	12 2½	10 11½	9 3	15	17	255	10 0× 6 6	10 6	20 3
3513	13180	14 8½	13 5½	11 9	20	17	340	7 0×10 0	13 0	25 3
3660	13730	13 2½	11 11½	10 3	17	17	289	10 0× 7 0	11 6	22 3
4096	15360	14 8½	13 5½	11 9	20	16	320	10 0× 8 0	13 0	25 3
4512	16920	14 8½	13 5½	11 9	20	18	360	10 0× 8 0	13 0	25 3
4705	17650	16 2½	14 11½	13 3	23	16	368	10 0× 9 0	14 6	28 3
5183	19440	16 2½	14 11½	13 3	23	18	414	10 0× 9 0	14 6	28 3
5572	20900	16 2½	14 11½	13 3	23	16	368	12 0× 9 0	14 6	28 3
6155	23090	16 2½	14 11½	13 3	23	18	414	12 0× 9 0	14 6	28 3
7256	27210	20 3½	19 0½	17 4	30	16	480	12 0×12 0	18 7	36 5
8218	30820	22 3½	21 0½	19 4	34	16	544	12 0×13 0	20 7	40 5

Marine Type Water-tube Boilers.—The latest development in some of the more important power stations where floor space is expensive, and where it is desired to install the maximum of power in the minimum of space and with the highest efficiency, is the use of the marine type water-tube boiler modified to suit land requirements.

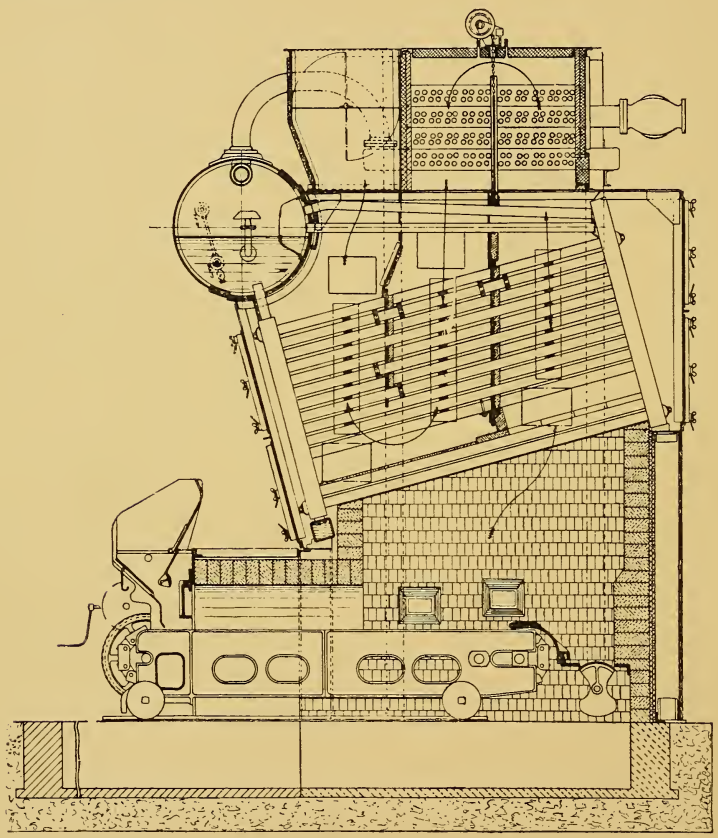


Fig. 14.

The evaporative capacity of every boiler is obviously governed by the amount of grate area provided, for with a given fuel and a given draught over the furnace, the coal consumption per square foot of grate area is, broadly speaking, a constant. In this respect water-tube boilers have an advantage over the drum type of

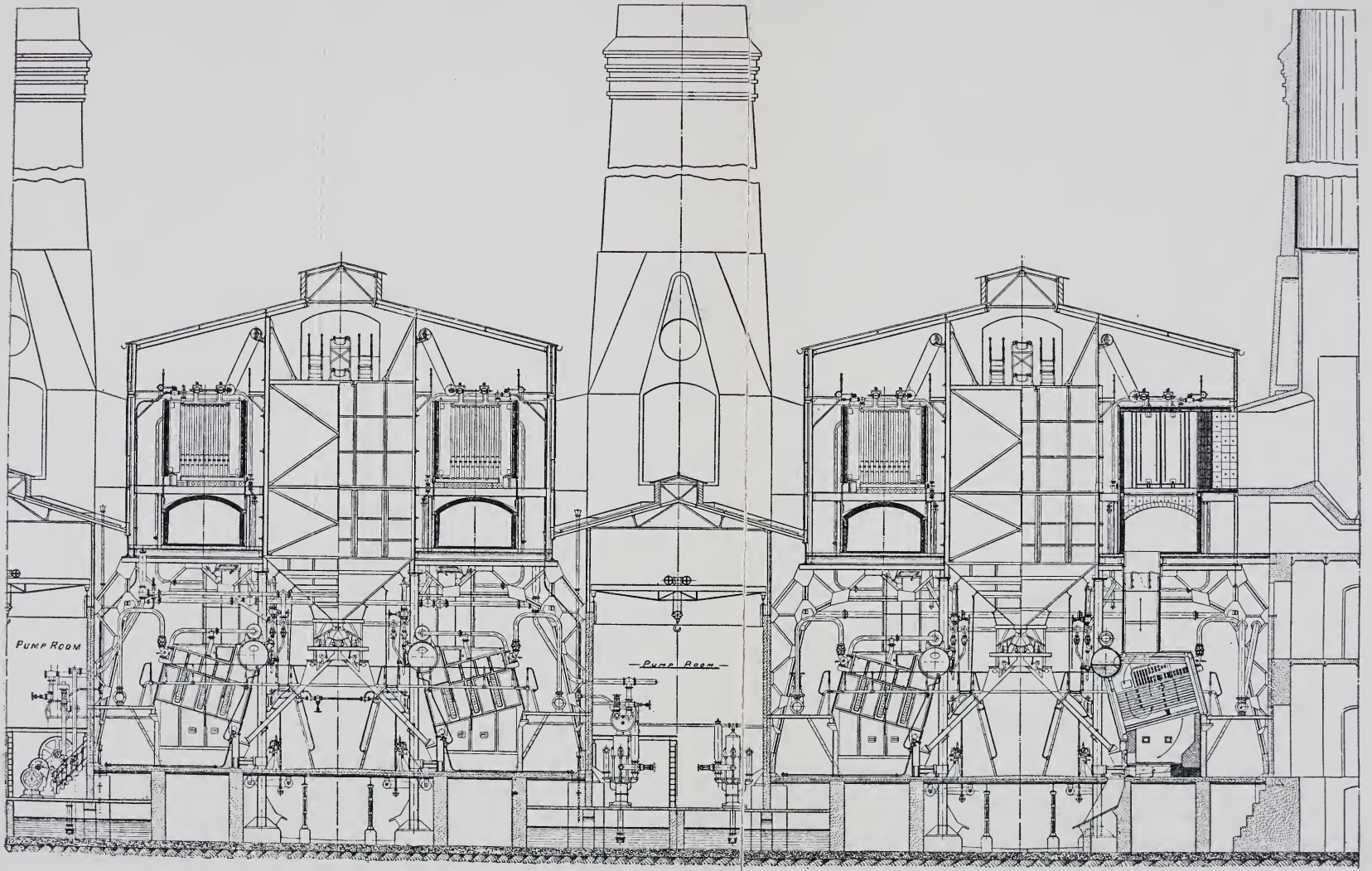


PLATE V.—GRAND CENTRALE, POWER HOUSE, BUENOS AYRES.

[*To face page* 63.

construction in that the refractory nature of the brickwork lining of their furnaces facilitates combustion, and therefore enables a somewhat greater quantity of coal to be consumed per square foot of grate area than in the case of the drum type of boiler.

It follows that a construction of boiler which enables practically the whole of the ground space occupied by it to be utilized for grate area, is that which will give the greatest evaporation per square foot of boiler-house floor.

Fig. 14 shows a Babcock and Wilcox marine type boiler as applied to land purposes. The furnace occupies the whole of the space underneath the tubes, and thus utilizes the ground space to the best advantage.

With this type of construction the boilers are entirely enclosed in an iron casing, which prevents any infiltration of air. There is a structural iron framing surrounding the pressure parts and firmly bolted to the foundations to which the casing plates are fastened. The sides of the furnace are composed of firebricks, the whole of the structure being surrounded by removable iron casings lined with fire-refractory material. Hinged doors at the front and rear permit of access to the handhole fittings, and doors in the side casings enable the ready removal of soot from the exterior of the tubes.

The compact nature of a boiler house equipped with marine type boilers is shown by reference to Plate V., which show the plant installed at Grande Centrale, Buenos Ayres.

Rating of Boilers.—Boilers are rated by their normal evaporation from and at 212° Fahr. or 100° C. By normal evaporation is meant evaporation at working pressure when burning a normal weight of coal per square foot of grate area, usually 16 to 18 lbs. per square foot; and with a normal draught at the chimney base, usually $\frac{5}{8}$ to $\frac{3}{4}$ inch of water. Water-tube boilers are capable of considerable forcing above this normal evaporation, and Table No. XVIII. shows the capabilities of the Babcock marine type both under normal working conditions and under emergency conditions.

With the Babcock "Express" type boiler, such as is used in torpedo destroyers, etc., evaporations as high as the equivalent of 12 to 14 lbs. of water from and at 212° Fahr. per square foot of heating surface have been obtained with a coal consumption of 40

to 50 lbs. per hour per square foot of grate area, the draught being from 2 feet to 2½ inches of water.

TABLE XVIII.

MARINE TYPE BOILERS FOR LAND INSTALLATIONS.

Heating surface in square feet.	Normal evaporation from and at 212° Fahr.	Maximum peak load evaporation, from and at 212° Fahr. with 1st class draught.	Grate area in square feet. Hand-firing.	Ground space occupied. Depth and width.
	lbs.	lbs.	lbs.	ft. in. ft. in.
1560	8300	11700	42·3	12 0 × 8 1
1817	9650	13600	49·3	12 0 × 9 1
2073	11000	15500	56·3	12 0 × 10 1
2330	12350	17500	63·3	12 0 × 11 1
2586	13700	19400	70·3	12 0 × 12 1
2843	15100	21400	77·3	12 0 × 13 1
3046	16150	22800	77·3	12 0 × 13 1
3321	17600	24900	84·3	12 0 × 14 1
3596	19050	27000	91·3	12 0 × 15 1
3870	20500	29000	98·3	12 0 × 16 1
4145	22000	31000	105·3	12 0 × 17 1
4420	23400	33000	112·3	12 0 × 18 1
4695	24900	35000	119·3	12 0 × 19 1
4970	26400	37000	126·3	12 0 × 20 1
5245	27800	39000	133·3	12 0 × 21 1
5520	29300	41000	140·3	12 0 × 22 1
5795	30700	43000	147·3	12 0 × 23 1

The evaporation from any given feed-water temperature can be easily corrected to the datum line of 212° Fahr. by the following rule:—

If H = total heat in B.Th.U. per pound of steam at the boiler working pressure from 32° Fahr.

W = lbs. of water actually evaporated per lb. of fuel.

T = temperature of feed water.

Equivalent evaporation per lb. of fuel from and at 212° Fahr.

$$X = W \times \frac{(H + 32) - T}{966}$$

Inversely, when as is usual, tables show the rated evaporation of boilers from and at 212° Fahr. the same formula may be used to assess the evaporation at any particular temperature, substituting X for W.

Boiler Efficiency.—This is the ratio of the heat units in the steam generated to the total heat units in the fuel used. The efficiency of any boiler depends on the rate of evaporation per square foot of heating surface, and this rate has a critical value, *i.e.* the efficiency

of any type of boiler will be less if the rate of evaporation be increased or reduced from this critical value.

The efficiency may be impaired through not selecting the most suitable type of boiler for the particular class of fuel available; by selecting a wrong class of mechanical stoker, or through congested flues or inefficient draught, air leakages through badly constructed brick walls and joints, damper slots, cold feed, and through radiation from the boiler parts. These various matters are treated later, with notes on the means of reducing or overcoming such losses.

Boiler Testing.—Boilers should be tested *in situ* after completion. In addition to the test of the coal-feeding plant, and ash removal, feed-water supplies, gauges, valves, and blow-down details, air tightness of flues and brickwork, adequacy and variability of draught, there remains the calorific balance, or thermal efficiency of the boiler. It is usual to specify a certain rated output of steam per boiler, with a guaranteed evaporation from and at 212° Fahr. per lb. of fuel of specified heat value, with a specified consumption of fuel per square foot of grate area, at a given draught measured by water column at the boiler damper; starting from a fixed water-level in the gauge and finishing at the same mark. The test should last over several hours so as to minimize the percentage error due to the possible slight difference in measuring this water-level in the gauge.

The following test-sheet on p. 66 may be used as a guide for such tests.

The following apparatus are necessary to conduct such a test:—

(*a*) Means of weighing coal. This is usually done by weighing out coal in baskets, tubs, or sacks. A steelyard platform machine checked against standard weights is usually provided.

(*b*) Means of weighing ash and clinker.

(*c*) Means of weighing the water fed into boiler; two graduated feed tanks provide the surer method. A water meter of the Venturi pattern may be used as a further check.

(*d*) Thermometers for measurement of feed-water temperature.

(*e*) Thermometer to measure superheat of steam.

TABLE XIX.

Result of test made at
by on 19 ,
in the presence of

Boiler No.				Furnace. F No.		Superheater. S. H. No.....		Economiser. E. No.	
Type.	Construction.	Heating surface.	Ratio heating surface to grate area.	Method of firing.	Grate area and dimensions.	Style.	Heating surface.	Type.	Heating surface.

Guarantees.

Summary of results.		Hours.	No. 1.	No. 2.
Duration.				
Fuel	Name and class	—	—	—
	Colliery district and price	—	—	—
	Volatile matter	per cent.	—	—
	Califoric value (dry)	B.T.U.	—	—
	Percentage moisture	per cent.	—	—
	Total fired (wet)	lbs.	—	—
	Total fired (dry)	,,	—	—
	Consumed per hour (wet)	,,	—	—
	Consumed per square foot grate per hour (wet)	,,	—	—
	Thickness of fire	ins.	—	—
	Ash by analysis	per cent.	—	—
	Ash, actual	,,	—	—
Steam	Average pressure	lbs.	—	—
	Saturated temperature	deg.	—	—
	Superheated tempeature	,,	—	—
	Degree of superheat	,,	—	—
Water	Temperature entering economiser	,,	—	—
	Temperature entering boiler	,,	—	—
	Total evaporated actual	lbs.	—	—
	Per hour, actual	,,	—	—
	Per hour, from and at 212°.	,,	—	—
	Per square foot H.S., from and at 212°	,,	—	—
	Per lb. (wet) coal, actual	,,	—	—
	Per lb. (dry) coal, actual	,,	—	—
	Per lb. (wet) coal from and at 212°	,,	—	—
	Per lb. (dry) coal from and at 212°	,,	—	—
	Factor of evaporation (including superheat)	—	—	—
Flue gases	Draught (and kind)	ins.	—	—
	Flue temperature, boiler damper	deg.	—	—
	Boiler house temperature	,,	—	—
	CO_2	per cent.	—	—
	CO	,,	—	—
	O	,,	—	—
Efficiency	Boiler with stoker	,,	—	—
	Boiler and superheater	,,	—	—
	Boiler, superheater, and economiser	,,	—	—

(*f*) Pyrometer, or nitrogen thermometer to measure the temperature of the flue gases leaving the boiler.

(*g*) Pressure gauges for steam.

(*h*) Chemical apparatus for measurement of composition of flue gases. A CO_2 recorder may also be fixed as a guide to the boiler superintendent.

(*i*) Draft gauge at grate and at boiler damper. Water gauges are most suitable.

(*j*) Chemical apparatus for measurement of calorific value of samples of coal used during testing.

On this point, and when available, it is better to send samples of the coal to a properly equipped laboratory where a speciality of this class of test is made.

The greatest care must be taken to ensure that the samples taken do fairly represent the bulk of the coal burnt during the test. A shovelful of coal should be taken from each basket or tub weighed out. These samples should be accumulated in a storage tub until the end of the test; they should then be emptied on to a cleanly swept part of the floor of the boiler house, thoroughly mixed and flattened. Two lines at right angles should be then drawn dividing the coal into quarters. Two opposite quarters are then removed and the remainder again mixed and similarly divided, and so on, until only a few shovelfuls remain. All lumps in the coal can then be broken until none of the coal is larger than "pea" or "bean" size. The mixing and quartering process should be continued until only a few pounds of coal remain. This remainder should be at once put into air-tight canisters, the covers of which must be sealed and also carefully marked for identification.

As the calorific value of coal depends largely upon the amount of ash, and as a higher percentage of ash is contained in dust coal than in large coal, it is essential that when quartering the coal samples as described above, the dust and small coal belonging to the quarters removed should also be removed. If this is not done, then the percentage of fine coal and dust in the final sample for the laboratory will be higher than is fair or than it should be.

The thermal balance would be set out as in Table No. XX.

TABLE XX.

Heat balance per 1 lb. of dried fuel.	B.Th.U.	Per cent
Total heat value of 1 lb. of dried fuel	—	—
Heat transferred to the water	—	—
Heat carried away by products of combustion . .	—	—
Heat carried away by excess air	—	—
Heat lost in evaporating and in superheating moisture mixed with the fuel	—	—
Heat lost by incomplete combustion	—	—
Heat lost by unburnt carbon in ash	—	—
Heat lost by radiation, superheating, moisture in air, hot ashes, and unaccounted for	—	—

Lay-out of Boiler House.—Having determined upon the type of boiler, and the size of unit best adapted for the power house, the designer has to consider the lay-out. There are several typical methods, these are—

(*a*) One boiler to each engine, giving the simplest arrangement of steam pipe, and adaptable to small units.

(*b*) Two boilers in each battery to each engine, as shown in Fig. 13; adaptable for larger units.

(*c*) Boilers arranged in two parallel rows, as shown in Plate I., where a boiler unit may consist of four individual boilers to each engine; adaptable for still larger units.

(*d*) Boilers arranged on two floors, as shown in Fig. 3, adaptable where space is of great value, and only recommended in exceptional circumstances on account of the cost of the structure, where one battery may become the boiler unit supplying one turbine.

(*e*) Boilers arranged as shown in Fig. 4, where each group or line of boilers, arranged at right angles to the turbine-room is the boiler unit. This design is necessary with very large turbines.

Either (*a*), (*b*), or (*c*) above may be used with the drum or fire-tube type. Such boilers are usually arranged in continuous batteries with the usual setting. A space of 3 feet is usually required between the shells of each pair of boilers, to allow for the side flues and firebrick division wall.

All the above methods are also applicable to the water-tube

type. It is customary, however, to instal water-tube boilers in pairs, with inspection ways from 3 to 5 feet wide between each pair, so as to enable access to be given to the various inspection and cleaning doors, and eye-holes. Attention must be given to the space left between the fronts of water-tube boilers and the boiler house walls or opposite faces of the range, so as to enable tubes to be replaced and stokers to be run out for repair and removal. Where space is restricted, windows, or Kinnear folding doors, can often be advantageously arranged opposite to the tubes of each boiler when arranged in single rows, so as to admit of cleaning, etc.

Banking Losses in Power Houses.—The following Table, No. XXI., gives the result of a test taken by Mr. E. T. Ruthven Murray at the Willesden Power House, England:—

TABLE XXI.

Time.	Coal percentage.				Evaporation.				Lbs. of coal per K.W. hour.		Weight of water per K.W. hour lbs.
	Firing to total.	Banking to total.	Bringing up to pressure to total.	Banking, etc., to firing.	Lbs. water per lb. fuel total.		Lbs. water per lb. fuel firing.		Firing.	Banking.	
					Actual.	From and at 212° F.	Actual.	From and at 212° F.			
	Per cent.	Per cent.	Per cent.	Per cent.							
8 a.m. to 4 p.m.	100	—	—	—	8·96	9·61	8·96	9·61	3·24	—	29·03
4 p.m. to 12 a.m.	93·6	—	6·4	6·9	8·81	9·30	9·41	9·91	3·17	0·217	29·77
12 a.m. to 8 a.m.	81·1	9·45	9·45	23·5	11·1	11·47	13·70	14·07	5·70	1·340	78·14
24 hrs.	94·2	1·1	4·7	6·29	9·14	9·65	9·70	10·22	3·34	0·210	32·44

In Table No. XXII. there is shown the results of a test by Mr. W. A. Vignoles, of Grimsby, England, giving the standby coal during one actual and two estimated weeks with different load factors. This shows how the variation of load factor affects the amount of coal required for standby purposes.

From various tests it has been found that the proportion of what may be called "preparation costs" in power houses, one

item of which is a proportion of the total fuel used, is a certain percentage of the total cost, and bears a certain proportion to the "running cost," which varies with the annual load factor. This has an important effect on the future economy of any power house design, and emphasizes the necessity of proportioning the size of units, both boilers and engines, and so arranging the pipework that these standby losses may be reduced to a minimum.

TABLE XXII.

Item.	Actual week.		Estimated week.		Estimated week.	
	Totals.	Per cent.	Totals.	Per cent.	Totals.	Per cent.
Unit generated per week	23,241	—	27,510	—	2520	—
Average per 24 hours .	3,320	—	3,930	—	360	—
Maximum load, K.W. .	440	—	640	—	150	—
Load factor	31·5%	—	25·6%	—	10%	—
Number of boilers in use	3	—	4	—	2	—
Total fuel per week, tons	79·75	100	92·0	100	13·75	100
Coal for banking fires in boilers required for peak load	1·5	1·9	3·0	3·3	1·5	10·9
Coal for banking fires on spare boilers and used in peat once a week .	2·6	3·2	2·6	2·8	1·0	7·2
Total coal used for standby purposes	4·1	5·1	5·6	5·6	2·5	18·1

Drum Boiler Settings. — Drum type boiler settings are now quite standardized; the underneath and side flues and the combustion chamber are, of course, lined with firebrick, and the drums are placed on specially formed seating blocks of pressed fireclay, having rounded noses abutting on the drum plate, so that while amply strong to resist crushing, only a minimum surface is in contact with the plate, thus allowing a maximum surface for inspection and external contact with the flue gases. These are shown in Fig. 15. Similar blocks are used to close in the tops of the side flues, which blocks are bonded into the side walls on suitable corbels. In boilers of these large dimensions especial care must be exercised to prevent air leakage from the outside, or short circuits of the flue gases from the under flue to the side flues. The boilers are arranged so that the front end plate projects beyond the brick face to enable the exterior angle ring to be clear of the brickwork and inspected. Since these boilers

must expand, it is frequently found that the joints between the facing brickwork and the boiler shell become defective and admit air. The Author has found a stemming of asbestos putty useful, being sufficiently elastic to permit of the breathing of the boiler without causing air leakage at that point. The blow-down neck (which must be of wrought steel and not cast) is also provided for in a special recess in the blow-down trench in front of the boilers. Special care must be taken to avoid air leakages through or over the walls forming this recess, since air leakages at this point are sometimes a course of undue deterioration of the shell plate. Where superheaters are used with drum boilers it is usual to fix them in the combustion chamber at the end of the boiler setting behind the back plate. Ample space must then be allowed at this point, so as not unduly to congest the space, and special care must be taken in fitting the firebrick quarles over the top of the chamber and around the superheater top box. In order to give the end plate of the boiler drum freedom, and to keep clear of the rivet heads it is usual to end the chamber cover pieces in an angle iron running parallel with the end plate, as shown in Fig. 16. This makes a neat finish to the chamber top, and prevents the boiler when expanded from compressing and dislodging the cover plates, and effectually prevents air leakage at this point. In setting the dry-back marine type a good space must be left between the back end plate and end wall of combustion chamber, so as to prevent the flames being reflected and beaten back on the tube-ends and burning them.

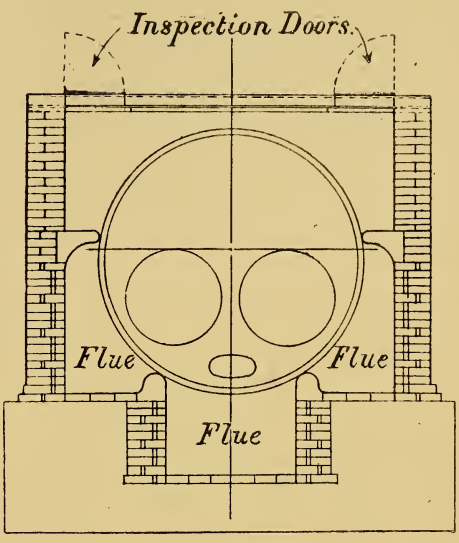


FIG. 15.

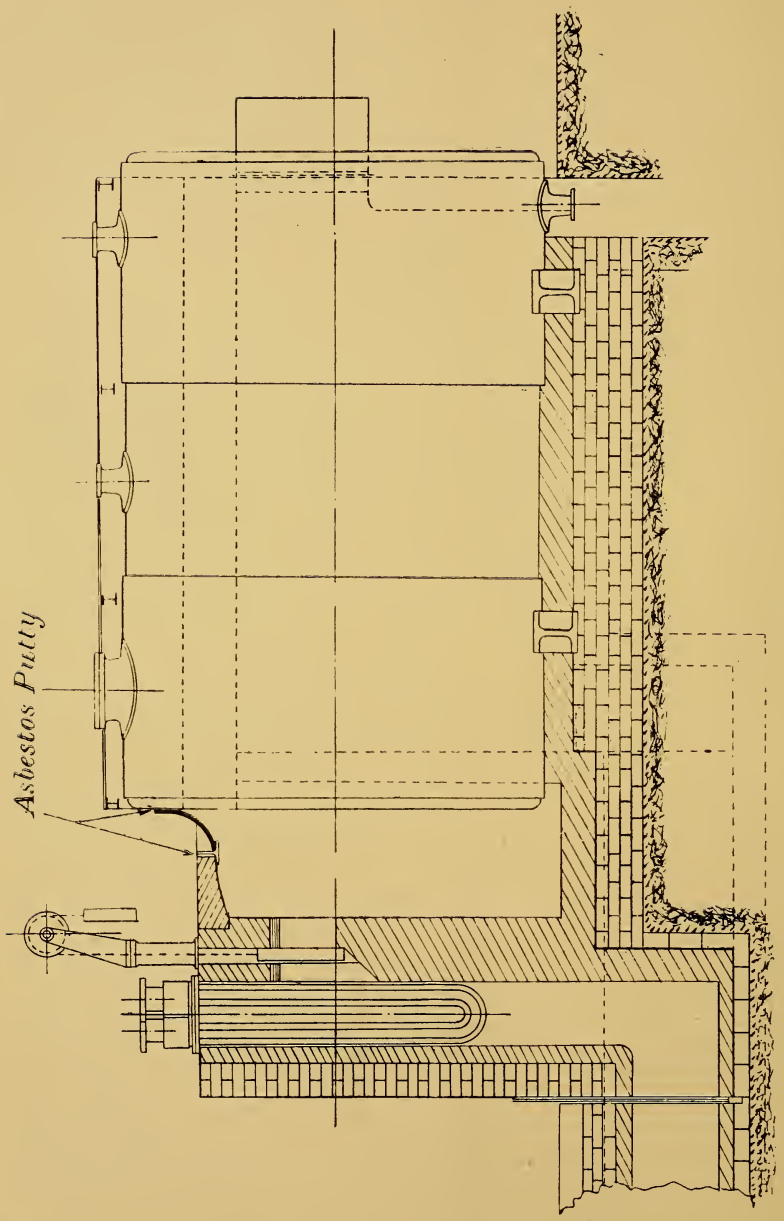


FIG. 16.

The ordinary setting viewed in end elevation usually finishes about two-thirds of the drum radius above the centre line, the exposed remainder of the drum being covered with non-conducting composition, a chase being left in the top of the boiler side walls to form a key between the lagging and the walls, and thus to prevent air leakage, as shown in Fig. 17. The Author has successfully used the method shown in Fig. 15, which has the advantage of providing an insulating space between the air and the drum (the drum being covered with removable asbestos mats,

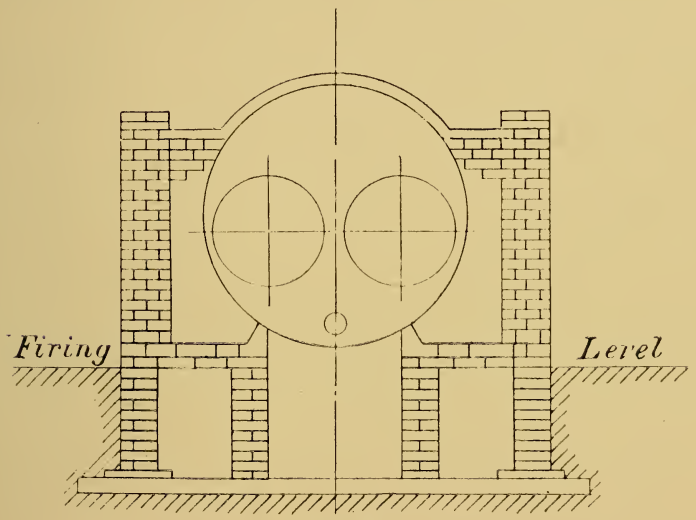


FIG. 17.

and enabling every seam, butt strap, and rivet head of the boiler to be examined easily without damaging the composition. Moreover the boiler tops are conveniently swept down, and a useful operating platform is provided.

Water-tube Boiler Settings.—In setting of water-tube boilers there are two principal methods: (*a*) the ordinary brickwork setting, and (*b*) the marine setting.

When using the former method great care must be taken to ensure good stock bricks, non-absorbent and of the same dimensions as the firebrick, except that they should be slightly thinner, so as to give a good bond and a thin joint. The bricks, therefore,

should be frogged (see specification of materials, p. 75). Outside bricks should be glazed to prevent porosity; failing which a good coat of bitumastic, tar compound, or similar protection should be laid on, which will soak into and seal up the pores and form an airtight skin. There being such a relatively large surface of brickwork exposed, good materials and good bricklaying are most essential in the interests of economy. The designer will find that if he carries the side walls up as shown in Fig. 15, and thus provides a flat platform over the boiler drum tops, he will also gain an advantage of easy inspection and absence of air leakage, with a durable casing, as was mentioned before.

The marine casings of water-tube boilers are iron plates bolted up to framing with firebrick lining, as previously mentioned, and have the merit of ensuring air-tightness and also of requiring less room. They are particularly useful in some parts of the world where it is difficult to obtain a good stock brick. Firebricks are usually shipped with the boiler, running about 3 tons per 1000 bricks.

A point of leakage frequently overlooked is where the dampers emerge from their guide frames. A practical method of reducing this is to carry an extension spindle up from the damper, extending the brickwork so as completely to envelope the damper, and bringing out the extension spindle (which must be long enough to emerge when the damper is right down) through a gland built into the brickwork. Dampers should always be man-handled from the boiler fronts, and, of course, counter-weighted.

The sidewalls of water-tube boilers have a lining of firebricks, $4\frac{1}{2}$ inches thick, set in fireclay, this lining being thoroughly bonded to the stock brickwork by headers at every fourth course, beginning at fire-bar level.

The arches over the fire doors, bridge, and hanging bridge over the tubes are built of firebrick set in fireclay, all carefully bonded to the side walls. The hanging bridge wall is built on iron supports built into the side walls, and is carefully fitted around the boiler drum. Baffles, forming divisions across the tubes, are formed of special firebricks grouted with fireclay and bonded to the side walls.

Specification of Materials for Boiler Settings. — Concrete is

usually specified to be composed of six measures of aggregate in a proportion of four of broken stones (to pass through a 2-inch ring) and two of sharp, clean sand to one of Portland cement. The materials to be accurately measured and mixed together in a dry state on a hard, clean platform, water to be then added to the above and the whole to be thoroughly mixed.

Mortar to be made in the proportion of one measure of lime of the best quality (measured before slaking) to 2½ measures of sand thoroughly mixed together.

Portland cement mortar to be mixed in the proportion of three measures of sand to one of cement. The cement to be of the best quality, perfectly cool, and not to weigh less than 112 lbs. per striked Imperial bushel of 2218 cubic inches, when lightly filled and without shaking down, the specific gravity of the cement when fresh burnt and ground to be not less than 3·15. The cement to be ground fine so as to pass through a sieve of 76 × 76 or 5776 meshes to the square inch, without leaving a residue of more than 3 per cent., and a residue of not more than 18 per cent. when sifted through a sieve of 180 × 180 or 32,400 meshes per square inch. A briquette, after immersion in water for seven days, to show a tensile strength in a testing machine of not less than 400 lbs. per square inch, and not less than 500 lbs. after twenty-eight days from gauging.

Sand to be clean and sharp, fresh water grit, washed free from loam and other impurities.

Firebricks to be machine made, sound, kiln burnt, of uniform size, free from cracks or flaws.

To ensure the best results, fireclay should be obtained from the same works as the firebricks, say one-half to three-quarters of a ton being required for setting 1000 bricks. The fireclay grout in which firebricks are set to be mixed very thin and the firebricks to be dipped in it (that is, the fireclay not to be laid on with a trowel) before being laid.

Glazed and facing bricks to be machine made, sound, square, and tough, kiln burnt, of uniform size, and to ring clearly on being struck together, entirely free from line or other defects. Not to absorb more than 7 per cent. of their weight of water after being thoroughly dried in an oven and then immersed in

water for twenty-four hours. These bricks to be thinner than the firebricks. No bats or broken bricks to be used, except for closers. All brickwork to be laid in line, with level courses. Joints in stock brickwork not to be more than $\frac{1}{4}$ inch thick.

Flues.—The areas of flues are usually from $\frac{1}{5}$ to $\frac{1}{7}$ the total grate area of the boilers delivering into them when hand fired. When forced draught is adopted, or other types of mechanical stokers having a high rate of combustion per square foot of grate area, then the area of the flue must be increased, and obviously should be proportioned to the quantity of fuel consumed.

It is good practice to allow 0·55 square foot of flue area for each 100 lbs. of coal burnt per hour. This gives a velocity of the flue gases of 30 feet per second, assuming the temperature of the escaping gases to be 550° Fahr., and the gases to contain from 10 to 12 per cent. of CO_2. If the gases are cooled down to 400° Fahr., then the flue area for each 100 lbs. of coal burnt per hour may be reduced to 0·44 square foot.

Flues must always be arranged as short and direct as possible, and preferably with an upward gradient toward the shaft—all flues must be constructed so as to offer least resistance to the flow of the gases, and must therefore be smooth inside, arranged with easy bends of good radius, with no sharp turns, and so built as to avoid eddies or cross-currents from boilers delivering into them. Flues are usually built up at 14-inch stockwork, set in mortar with a $4\frac{1}{2}$-inch firebrick lining set in fireclay, bonded by headers at every fourth course into the main walls of the flue. The arrangement of dampers must be such as to permit of sections being shut down periodically, without laying off an impracticable proportion of the total boilers installed; and for cooling down for the removal of soot and ashes, this is specially necessary in the tropics. Access doors must be suitably arranged for this purpose, and in designing the boiler lay-out access from outside the flue must be given so as to permit the removal of the soot by barrows, without unduly upsetting the cleanliness of the boiler-room. Special care must be given to access doors and frames, damper frames, and spindles to ensure air-tightness. Dampers should preferably be of the swivel type, with extended spindles, but where drop dampers are necessary extended spindles must also be used so as to recover the damper

in the event of its operating chain breaking. In lining out the flues with firebrick thin joints must be used, and care must be taken to select a stock brick (with frog) of slightly thinner dimensions than the firebrick so as to ensure a good bond. It is good practice to fix headers at every fourth course of the 4½-inch firebrick lining, bonding into the stockwork, so as to prevent any bulging and collapsing of the firebrick lining.

Mechanical Stokers.—In power houses it is now almost imperative, with the large grates adopted, to use some form of mechanical

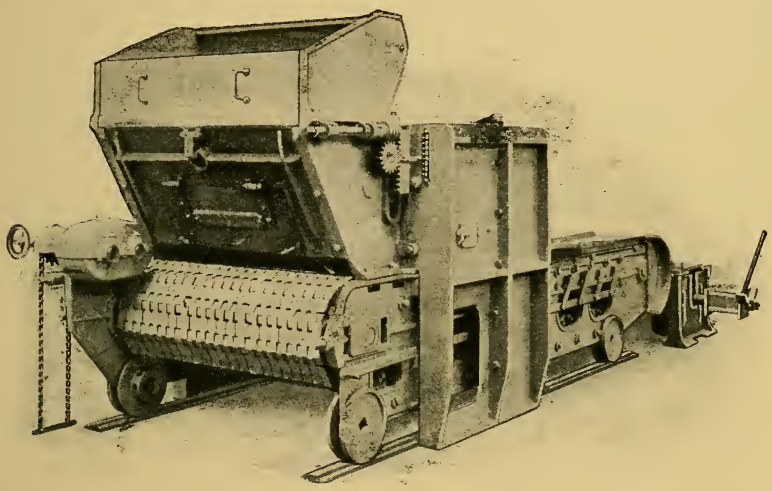


Fig. 18.

stoker. For bituminous coals nothing can really beat the chain-grate type, which ensures an even distribution, is easily controlled and repaired, and, owing to the revolving motion, gives a long life to the links. These are, of course, only adaptable to water-tube boilers, and they are usually now given an inclination towards the fire bridge so as to give a deeper combustion chamber at that end. The only objection to them is that at very light loads the fire is thin, and there is a tendency to form air cavities with an excess of CO.

Reference to Fig. 18 will show that the stoker, when working on a variable load, is provided with air shutters at the rear end. These shutters can either be operated by a single lever or two

levers. Thus on light loads the air supply to the rear of the stoker can be regulated and restricted so that practically the same percentage of CO_2 in the furnace gases can be maintained as at times of heavier loads.

The chain-grate stoker is driven from a light countershafting by a very small motor or steam engine, from which motion is given to the stoker rocker by a motion rod working from an eccentric, or, better still, by means of a Morse silent chain-drive. For each stoker, up to a width of 7 feet, 1 B.H.P. is allowed, and for

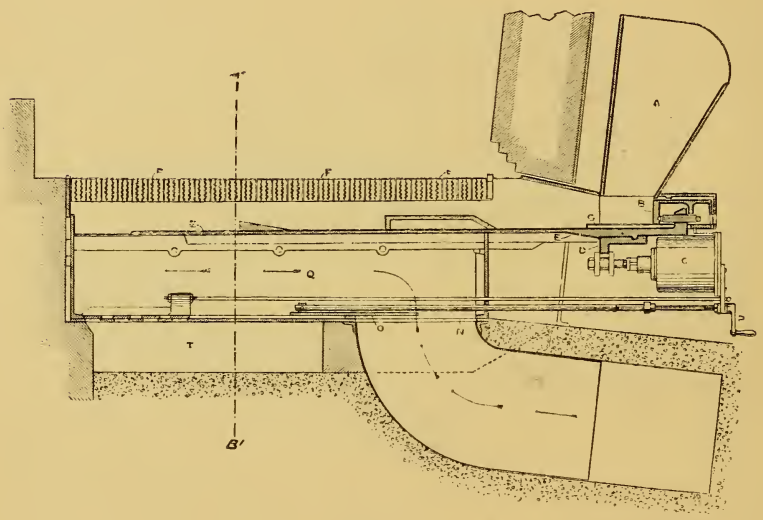


Fig. 19.

stokers of greater width from 1½ to 2 B.H.P. per stoker. This also includes power absorbed by the countershafting.

In the underfeed stoker, the fuel is deposited in the hopper A, shown in Fig. 19, and taken under the fire by a reciprocating sliding bottom running the full length of the trough. The coal rises from the trough, and is distributed thence to the sides of the grate by moving bars. The coking and also the burning coal is constantly carried by the moving bars to dumping trays along each side wall, where the clinker and ash are deposited. These trays are hand operated from the boiler face, enabling the ash and clinker to be discharged. The sliding bottom in the trough shown

in Figs. 19 and 20, is driven by a steam cylinder, and the number of strokes can be varied from one in three minutes to fifteen in one minute, each stroke carrying about 6 lbs. of coal. There is thus a very considerable range in the amount of feed. Air enters the grate from the forced-draught air trunk shown in Fig. 18, and is controlled by a wind gate shown at O. The air enters a wind box, Q, passes upward along each side of the trough, and is discharged through an aperture, R (Fig. 20), and also through the

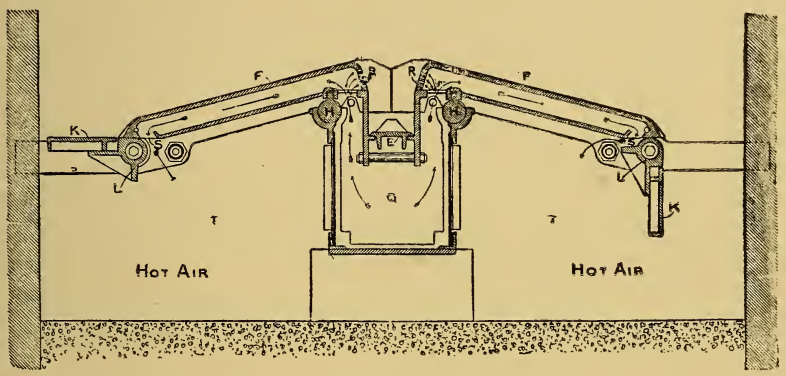


FIG. 20.

hollow bars into the ashpit, whence it rises through the space between the bars, to the grate. The bars are thus kept cool and the air temperature in the ashpit is raised to about 350° or 400° Fahr.

Where anthracitic coal has to be used the under-feed type of stoker is an excellent machine, and can be adapted for either internal combustion or water-tube boilers with very good results. For the latter type it is necessary to provide forced draught blowers for this purpose with distributing air trunks to the various furnaces.

Draught Gauges.—It is well to fix a small draught gauge to each grate, for the instruction of the stoker or boiler-house foreman, as well as a main draught-water gauge at the base of the uptake or chimney. These should preferably be of the water column type.

CO_2 Meters.—There are several types of carbon-dioxide

recorders, one of which should always be fixed to each range of boilers with a tube from each boiler flue to the recorder, the exit pipe to provide the necessary pressure gradient being led into the chimney. These tubes should be of glass so as to permit of easy examination, since they are so likely to be choked with dust, soot, and fine ashes.

The Sarco recorder may be taken as illustrative. A $\frac{3}{4}$-inch pipe from the combustion chamber of each boiler, with control cocks on each branch, is led to the instrument, and another pipe of the same size is led from the instrument to the chimney. The power required to draw and deal with the gas samples is obtained from a fine stream of water with a head of about 2 feet (3 to 5 gallons per hour being required). By this means the gases are drawn through certain parts of the instrument and made to bubble through a solution of caustic potash (sp. gr. 1·27), by which process the carbon dioxide is absorbed rapidly and completely. According to the amount absorbed so is the height of travel of a float varied, and by means of a pen an automatic record is taken on a chart: the height of the lines marked by each displacement of the float registering the percentage of CO_2.

Such recorders should be checked periodically by more elaborate laboratory apparatus.

Although theoretically a high percentage of CO_2 in the flue gases points to a high efficiency of combustion, discretion must be used in placing too great reliance on this one factor. Certain coals, in practice, cannot be burnt efficiently without a fairly high excess of oxygen in the combustion chamber with a corresponding diminution of CO_2, and in the case of such coals better results are obtained with a comparatively low percentage of CO_2 in the furnace gases.

For any particular class of coal the power house engineer, by a series of careful tests, should determine the best practical percentage of CO_2 which must be obtained, and then give instructions for that figure to be worked to.

The following analysis of the average losses found in the conversion of one pound of coal into electrical energy was given by H. G. Scott, in the *Transactions of the Amer. Inst. of Electrical Engineers.*

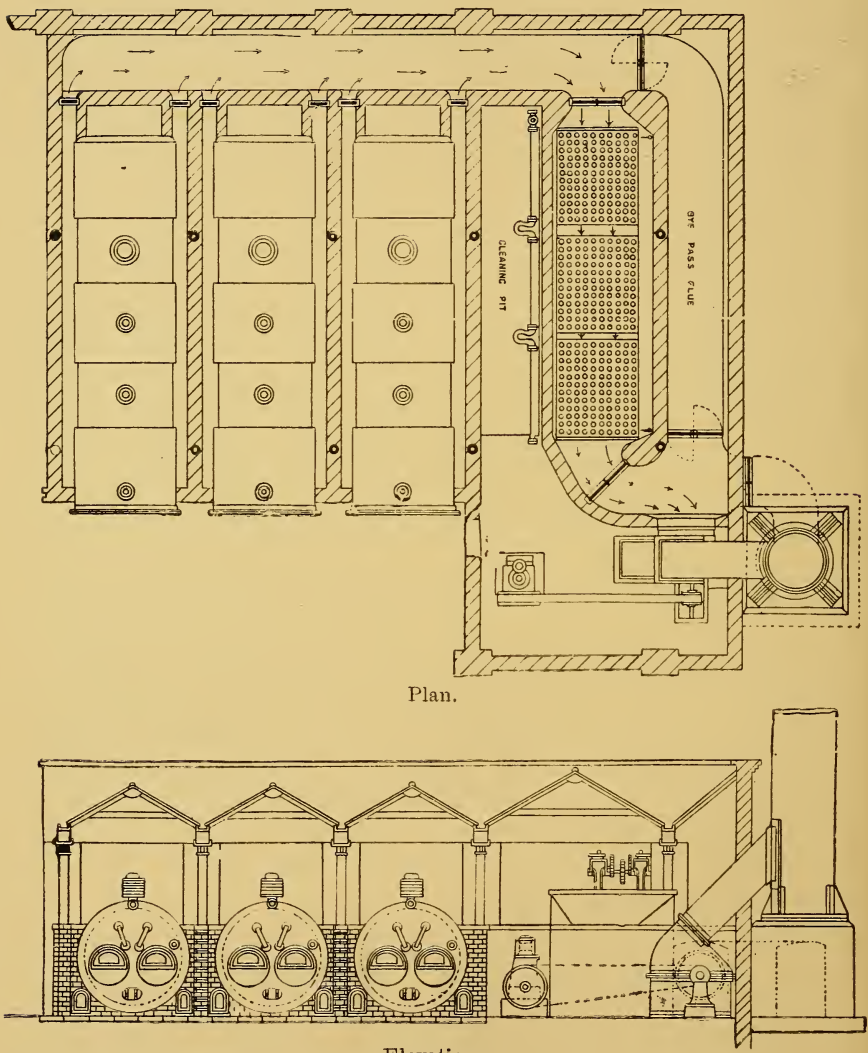
TABLE XXIII.

	B.Th.U.	Per cent.	B.Th.U.	Per cent.
B.Th.U. per pound coal supplied	14,150	100·0	—	—
Loss in ashes	—	—	340	2·4
Loss in stack	—	—	3212	22·7
Loss in boiler radiation and leakage	—	—	1131	8·0
Returned by feed-water tests	441	3·1	—	—
Returned by economiser	960	6·8	—	—
Loss in pipe radiation	—	—	28	0·2
Delivered to circulator	—	—	223	1·6
Delivered to feed pumps	—	—	203	1·4
Loss in leakage and high-pressure drips	—	—	152	1·1
Delivered to small auxiliaries	—	—	51	0·4
Heating	—	—	31	0·2
Engine friction	—	—	111	0·8
Electrical losses	—	—	36	0·3
Engine radiation losses	—	—	28	0·2
Rejected to condenser	—	—	8524	60·1
Other power house auxiliaries	—	—	29	0·2
Total B.Th.U.	15,551 14,099	109·9 99·6	14,099	99·6
Delivered to bus-bars	1452	10·3	—	—

Mechanical Draught.—In the design of boiler plant in power houses it is well to remember (*a*) that some of the plant is always at work throughout the year; and (*b*) that flues must be cleaned and chimneys or shafts repaired without stopping or imperilling the supply; (*c*) the variations of load are better met by an easily regulated artificial draught; peak loads, and emergencies can be better dealt with, and the commercial value of any battery of boilers can be thus raised by working on the overload capacity of the boilers though doubtless at the sacrifice of some efficiency during such periods.

Therefore in a completed design there should always be an alternative shaft, unless the whole power house is built on the bulkhead principle. For small installations two small steel shafts with forced or induced draught plant are to be preferred to one larger or more costly brick shaft with natural draught. Again, in most cases, owing to the variability of the electrical output, the range of evaporation of the boilers is often a wide one. Means of varying the draught are therefore desirable. The energy required

to drive the auxiliary draught plant is more than compensated for by the useful absorption of the heat units in the flue gases by



Plan.

Elevation.

FIG. 21.

economisers, the final temperature of the gases at the exit from the economiser being reduced to a much lower figure than would

of course be possible under conditions of natural draught and a not unduly high chimney. Generally speaking, induced draught fans are adopted for bituminous fuels with chain grate or other open grate types of stoker: and forced draught fans for anthracitic coals with closed grates. Fig. 21 shows a typical arrangement of induced

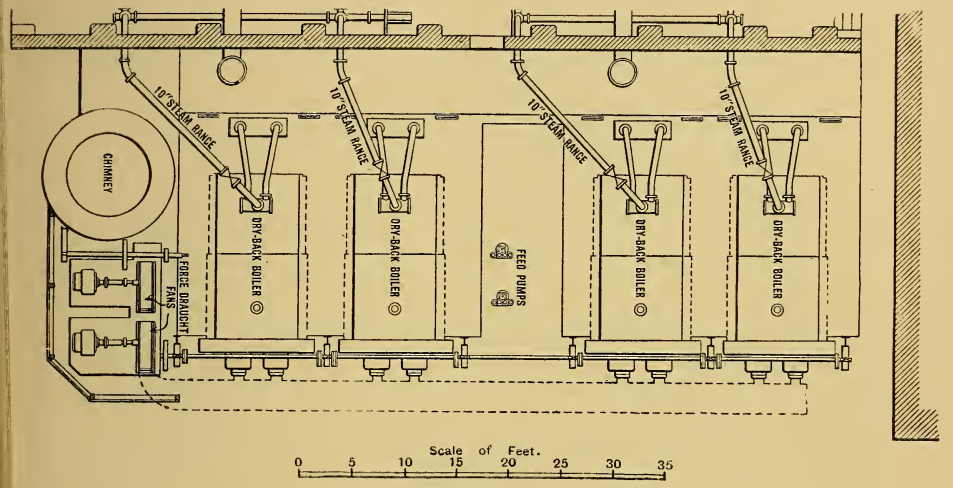


FIG. 22.

draught fans with motor-drive and bye-pass flue, and Fig. 22 a typical arrangement of forced draught fans with air trunk and ducts for closed grates.

Power required for Fans.—To calculate the K.W. required to drive a fan supplying any particular battery of boilers:—

If D = density of flue gas in lbs. per cubic foot,

A = area of discharge opening in square inches,

V = velocity of gases in feet per second, *i.e.* the peripheral speed of the fan blades;

$$\text{then K.W. input to motor} = \frac{DAV^3}{2{,}454{,}000}$$

assuming 55 per cent. efficiency of fan and 92 per cent. average efficiency of motor.

Another method is given by the following formula:—

$$\text{Brake H.P.} = \frac{W \times C \times A \times P \times 5{\cdot}2}{60 + 33{,}000} \times \frac{100}{E}$$

where W = average weight of coal consumed per hour,

C = number of cubic feet of air required per lb. of coal, say, under ordinary working conditions, 300 cubic feet,

A = coefficient of volume of gas at flue temperature (T) as compared with volume of air at 50° Fahr. $(T_1) = \frac{461 + T}{461 + T_1}$, the temperatures being taken in both cases as temperatures absolute,

P = pressure or draught in inches of water at the fan.

$\frac{100}{E}$ = efficiency of the fan.

5·2 = constant for converting the pressure or draught as read on the draught gauge into pressure in lbs. per square foot.

The average efficiency of fans varies from 52 to 55 per cent., and if one substitutes the former figure and takes 300 cubic feet of air as being required per lb. of coal, the formula resolves itself into

$$\text{H.P.} = \frac{W \times A \times P}{660}$$

This figure represents the brake H.P. required to drive the fan, and does not take into account the efficiency of the motor.

For batteries of boilers aggregating 100,000 lbs. evaporation per hour or more this may be expressed as requiring a fan-draught motor of 0·55 B.H.P. per 1000 lbs. evaporated per hour.

It is essential to duplicate the fans and motors so as to have a complete reserve in the event of any failure of the one set.

Fans may be supplied with $\frac{1}{2}$, $\frac{3}{4}$, or complete steel housing according to the position in which they are to be placed, but it is a point of good design so to arrange them as to keep the bearings away from the flue gases. Owing to the heat conducted from the fan blades and spider, the bearings usually have to be water-jacketed. Motors can either be of the squirrel cage 3-phase slip-ring type, or direct-current. The latter lends itself more readily to speed variation, which is essential since the delivery of air must vary somewhat as the load on the power house (though not directly, the

power required by the fan being proportionate really to the cube of the speed). This is especially easy with a double-wound armature. But the squirrel-cage motor can be given, say, three regular speeds by means of a controller and resistances. The motors are usually direct coupled to the fan shaft with water-jacketed bearings as shown in Fig. 23, and are sometimes rope driven as shown

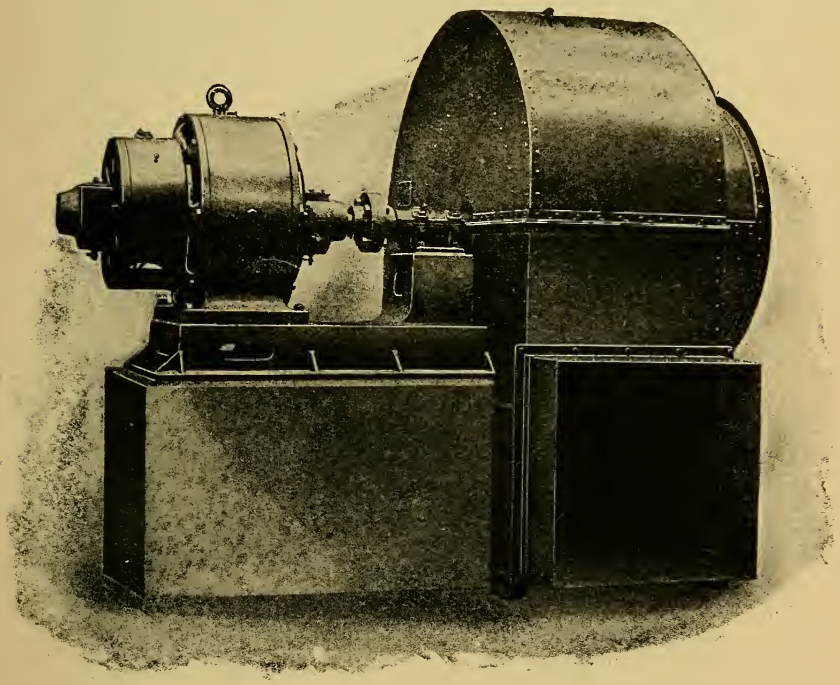


Fig. 23.

in Fig. 24. The former should be adopted whenever practicable, owing to the consequent reduction of space required.

Table XXIV. gives the capacities of some standard sizes of Sirocco induced draught fans (which may be taken as typical of high-class fan practice) together with the speeds and approximate B.H.P. required. The first columns deal with temperatures of 500° Fahr., and apply to cases where economisers are not used, and where the flues are of normal area, and without objectionable bends. The latter columns deal with flue temperatures of

400° Fahr. and apply where economisers with moderate heating surface are used, and thus a higher water gauge is required to overcome the extra flue resistance. In both cases the B.H.P.

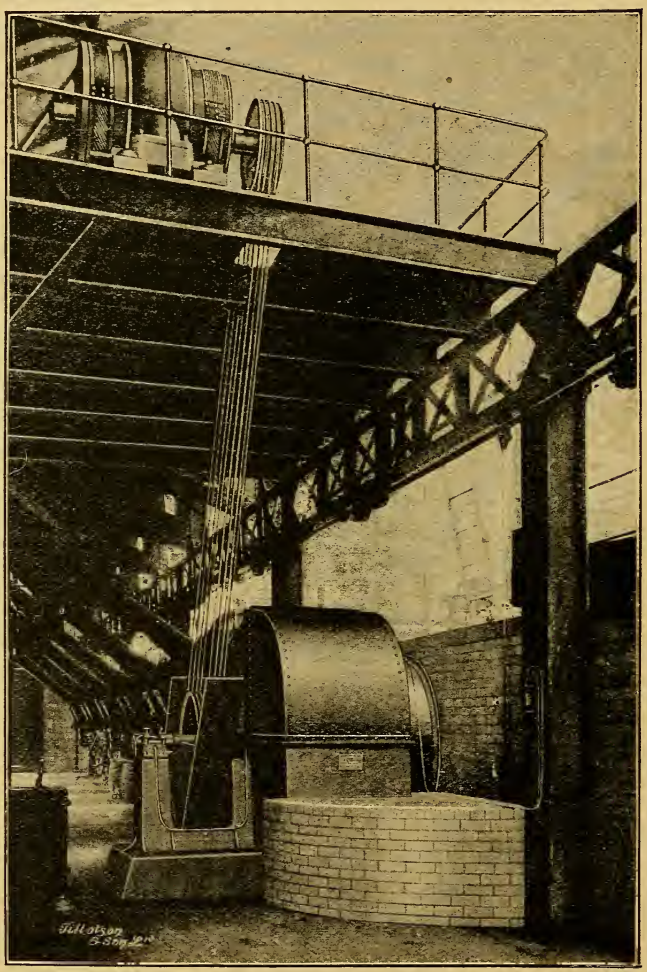


Fig. 24.

given is an outside figure, and if variable speed motors are adopted, it will be found that under usual and normal conditions of working, the H.P. will work out a good deal below that given

in the table. It is the rule, however, to provide motors of liberal rating, particularly in the case of variable speeds, so that when necessary the draught power can be increased to meet a sudden increase of load on the boilers, or a change in the class of fuel.

TABLE XXIV.

Temperature of gases 500° Fahr., water gauge 1½ ins.			Temperature of gases 400° Fahr., water gauge 2 ins.			
Amount of coal in lbs. per hour.	B.H.P.	Speed.	Amount of coal in lbs. per hour.	B.H.P.	Speed.	
800	4	1000	—	—	—	The price of induced draft fans for direct coupling to, but exclusive of motors or engines, is approximately £100 per 5000 lbs. of coal per hour.
2,000	9	680	2,300	13	730	
3,800	18	505	4,300	25	560	
6,100	30	410	7,000	40	450	
7,500	37	370	8,500	49	410	
9,000	45	340	10,000	59	375	
10,000	49	315	11,000	65	345	
11,500	54	290	12,000	70	315	
13,000	60	270	14,000	82	295	

Chimney Shafts for use with Forced or Induced Draught.—The dimensions of shafts in connection with artificial draught may be based on a gas velocity in the vertical shaft of 30 feet per second. Each pound of coal burnt, yields from 13 to 30 lbs. of gas, the volume of which of course varies with its temperature.

The following Fig. 25 shows the quantity of air delivered with increasing draught under the same temperature conditions,

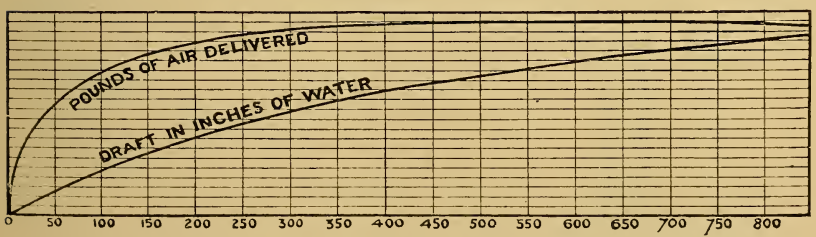


FIG. 25.

in a 100-foot shaft, the external atmospheric temperature being 60° Fahr.

With forced or induced draught plants, the shaft has no other

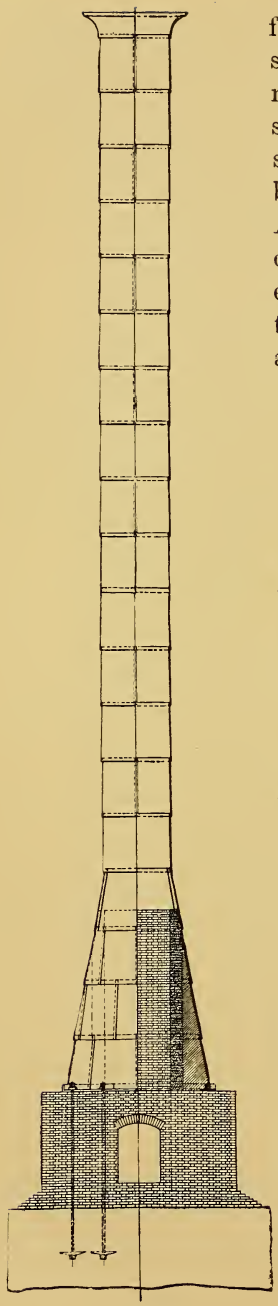


Fig. 26.

function than to discharge the gases at a sufficient height so as not to create a nuisance. Fig. 26 shows a typical steel shaft in elevation, Fig. 27 the plan of same, and Fig. 28 a section through the base plate showing formation bolts. Another advantage lies in the portability of such a shaft, in its small weight and easy erection and subsequent inspection, the weight of a steel shaft 100 feet high and 9 feet internal diameter weighing only

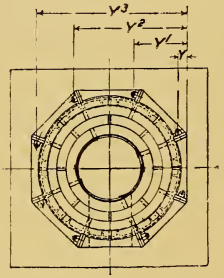


Fig. 27.

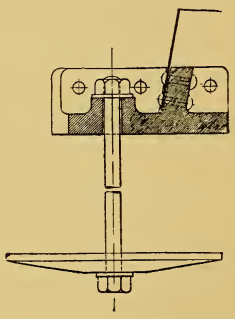


Fig. 28.

18 tons exclusive of brickwork. On the other hand, it requires frequent scraping and painting especially in manufacturing areas where traces of sulphuric acid and other corrosive agents are found in the atmosphere.

The following general specification for a 100-foot shaft may be taken as typical. Such a shaft will deal with a maximum load of 5000 K.W. on a basis of 4 lbs. of hard steam coal per K.W. hour.

(*a*) The shaft to have an internal diameter of 9 feet measured inside the firebrick lining, and a clear height of 100 feet above grate level. The shaft to be coned from the base to a height of about

40 feet, the diameter at the base to be about 15 feet. To be constructed in sections as follows :—

Bottom section, 45 feet of $\frac{5}{16}$-inch plates.
Top section, 40 feet of $\frac{1}{4}$-inch plates.

The plates to be well riveted together and lined with firebrick to a height of 35 feet from the base. The whole structure to have a factor of safety of 5, based on a maximum wind pressure of 50 lbs. per square foot.

(*b*) The base to be built up of segments of good grey coloured close-grained pig-iron, secured by foundation bolts to a brick-work plinth lined with firebricks into which the flues are to be led.

(*c*) The shaft plates to be shaped to proper curvature by rolling cold, and the whole to be laid out accurately at the maker's works and all rivet holes drilled. The plates to be made from the best mild acid open-hearth steel, with a tensile strength of 28 to 32 tons per square inch, and an elongation of not less than 20 per cent. in a test length of 8 inches.

(*d*) The cap to be made from cast-iron, belled and reinforced by steel angle stiffeners.

(*e*) The rivets to be made from open-hearth acid steel, with a tensile strength of 24 to 28 tons, and an elongation of not less than 28 per cent. in a length of 2 inches. The usual bending and flattening tests are also to be specified.

(*f*) The shaft is usually provided with a safety ladder, rivetted to the exterior and facilities afforded for painting by fixtures attached to the cap from which the usual painter's cradle may be swung.

(*g*) Lightning conductors and roses are provided in the usual way.

Dimensions of Steel Chimney Shafts.—There must be a certain relation between the exposed area of shaft, and its height, weight, and breadth of base to withstand successfully the overturning moment due to severe wind pressure. This is expressed by the formula

$$W = C\frac{dH^2}{B}$$

where W = weight of shaft in pounds,
C = coefficient of wind pressure per square foot of area, usually taken at a value of 28 for circular shafts,
d = average external diameter of shaft in feet,
H = height in feet,
B = breadth of base in feet.

The size of foundation bolts is obtained from the formula

$$S = \frac{C \times d \times H^2}{2} - \frac{W \times B}{2}$$

where S = total stress on all the bolts (this should never exceed 8000 lbs. per square inch),
C = coefficient as in the above formula,
d = average diameter in feet,
H = height in feet,
W = total weight of shaft in pounds above the *cast-iron base*,
B = diameter of base plate in feet.

The stress on each foundation bolt can then be determined from S in the following manner—

$$S_1 = \frac{S}{2(y \times y_1 \times y_2)}$$

where $y + y_1 + y_2$, etc., are the dimensions (in feet) measured from one edge of the base plate to the successive centres of the foundation bolts (see Fig. 27).

Natural Draught Chimneys.—The approximate sizes of natural draught shafts for boiler plants of given total evaporative capacities per hour under average practical conditions are given in the Table XXV. on p. 91.

The last-named in the table represent the advisable limit of size of plant delivering into any one shaft; as before mentioned, for large plants, two or more shafts should be provided.

Draught in Chimney Shafts.—The draught of a chimney depends, of course, on its effective height, the area being suitably proportioned to deal with the volume of gases, since it is proportional

to the difference between the weight of the column of air outside and that of the column of lighter gases inside.

TABLE XXV.

Diameter in inches.	Height of shaft in feet above grate level for evaporative capacities (in pounds per hour).						Side of square.	Effective area.	Actual area.
	100 ft	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	ins.	sq. ft.	sq. ft.
48	10,500	11,000	11,700				43	10·44	12·57
54	13,500	14,200	15,100	16,600			48	13·51	15·90
60	17,000	17,800	19,000	20,800	22,500		54	16.98	19·64
66	20,900	21,900	23,300	25,500	27,600	29,500	59	20·83	23·76
72	25,100	26,300	28,100	30,700	33,200	35,500	64	25·08	28·27
78	29,900	31,200	33,300	36,400	39,300	42,000	70	29·73	33·18
84	34,900	36,500	38,900	42,600	46,000	49,200	75	34·76	38·48
90	40,400	42,500	44,900	49,200	53,100	56,800	80	40·19	44·18
96	46,200	48,500	51,600	56,300	60,900	65,800	86	46·01	50·27
102	—	—	58,400	64,000	69,100	73,900	90	52·23	56·75
108	—	—	65,800	72,100	77,900	83,200	96	58·83	63·32
114	—	—	73,800	80,700	87,100	90,100	101	65·83	70·88
120	—	—	—	89,700	96,900	103,600	106	73·22	78·54
126	—	—	—	99,300	107,200	114,600	112	81·00	86·59
132	—	—	—	109,300	118,100	126,200	117	89·19	95·03
138	—	—	—	119,800	129,700	138,300	122	97·75	103·86
144	—	—	—	130,800	141,000	151,000	127	106·72	113·10

The effective draught in inches of water may be found from the following formula:—

$$D = H\left(\frac{7{\cdot}6}{T} - \frac{7{\cdot}9}{T_1}\right)$$

where D = draught in inches of water at base of shaft,

H = height of shaft above grate level,

T = absolute temperature in degrees Fahr. of external air, *i.e.* T + 461,

T_1 = absolute temperature of internal air, *i.e.* T_1 + 461.

Coal Bunkers and Conveyors.—The next detail to consider is the coal-storage and coal-conveying gear. There are various matters which must have the designer's attention.

(*a*) If the power house be situated in a position where coal is only infrequently delivered and where a plentiful storage must be made, then the method of storage will depend on whether the available fuel is bituminous or anthracitic (*i.e.* whether it will lose

in value by open storage or not) and whether the general climate is hot and dry, or hot and moist, or generally humid.

(*b*) Dependent on the above it will be determined whether to provide covered silos at ground level or below it, or whether this expense may be saved and the coal dumped on a paved storage ground in the open.

(*c*) The means of unloading, *i.e.* whether a wharf beside which ships may unload, or a railway siding and the height and level of embankment with respect to the firing level. A description of a very complete unloading plant for a large power house at Buenos Ayres in given on page 39.

(*d*) The overhead storage should be reduced to a reasonable limit since the additional steel work necessary to carry the large weight is costly and usually unnecessary, except in special cases of very costly sites.

(*e*) Subdivision of storage and other bunkers in the event of spontaneous combustion of coal, so as to permit of the compartment being rapidly emptied and to prevent the fire spreading. Means of ascertaining the temperature at the bottoms of the bunkers by suitable thermometer pockets of shafts should be provided.

(*f*) Arrangement of bunkers to trim and empty automatically, remembering that the angle of repose of tipped small coal is from 30° to 60° from the horizontal, depending on its quality and dryness.

(*g*) Adequate ventilation of all bunkers.

There are various appliances for unloading from ships. Either a pier may be constructed in the case of large power houses so that large steamers may lie alongside at all times of the tide as shown in Plate I. (page 13) or a wharf can be constructed to berth lighters and smaller ships, or, in rarer cases, where there is sufficient depth of water, large cargo steamers. Unloading may be effected either by electrically operated grabs or by a hopper directly feeding a conveyor. The coal may then be distributed either by coal waggons, as in the case of the Greenwich station of the London County Council, into coal silos, or by automatic tipping tray conveyors. Two cranes, each fitted with two motors, one of 50 H.P. for lifting and one of 10 H.P. for slewing, will

unload 2000 tons in 24 hours. In some cases a Temperley transporter is used if the coal is distributed in the open, or if the run back from the wharf to the power house is at some distance or at a high level. Suppose that the coal is stored in a silo, then the capacity must be arranged to hold a month's supply or sufficient for a longer period according to the regularity of the coal delivery, and the dependence on storm-bound ships, strikes, and so forth. The silos may be constructed as shown in Plate I. which shows a coal store designed by Mr. John H. Rider for the Greenwich power house.

Ferro-concrete Bunkers.—The silo with a capacity of 2000 tons is built of ferro-concrete with bulk heads dividing the bunkers and with self-trimming bottoms and mouthpieces with hand-operated valves feeding the coal into a filler, thence into gravity bucket conveyors, which in turn carry the coal to the overhead feeding bunkers. Each conveyor has a carrying capacity of 40 tons per hour, and is driven by a 25 B.H.P. squirrel cage 3-phase motor, 475 R.P.M., 220 volts between phases. The weight of coal is checked on weigh bridges with 5-feet dials, which are accurate within 3 lbs. on a load of 5 tons.

In other cases where coal is rail borne, the silos can be so arranged that the waggons can empty directly into the bunkers, approaching from the siding by a ramp, embankment, or viaduct; or, where the conditions are such as to render silo storage unnecessary, then the waggons can discharge into a filling hopper from which the coal is taken by cross conveyors to the main conveyor as shown in Fig. 29. This represents the method adopted by the Author for the Bahia Blanca (Argentina) power house for the B. A. and Pacific Railway. The capacity of the filling hopper and conveyor is 50 tons per hour; the coal passes through a coal crusher which, with the cross conveyor, is driven by a 20-B.H.P. squirrel cage 3-phase motor, 565 R.P.M. 500 volts between phases. The cross conveyor feeds into one or other of the two main gravity bucket conveyors, each with a capacity of 50 tons per hour, each driven by a 10-B.H.P. squirrel cage 3-phase motor 565 R.P.M.

Too large a storage overhead is costly on account of the stiffer steel work necessary, involving heavier stanchions and bracings.

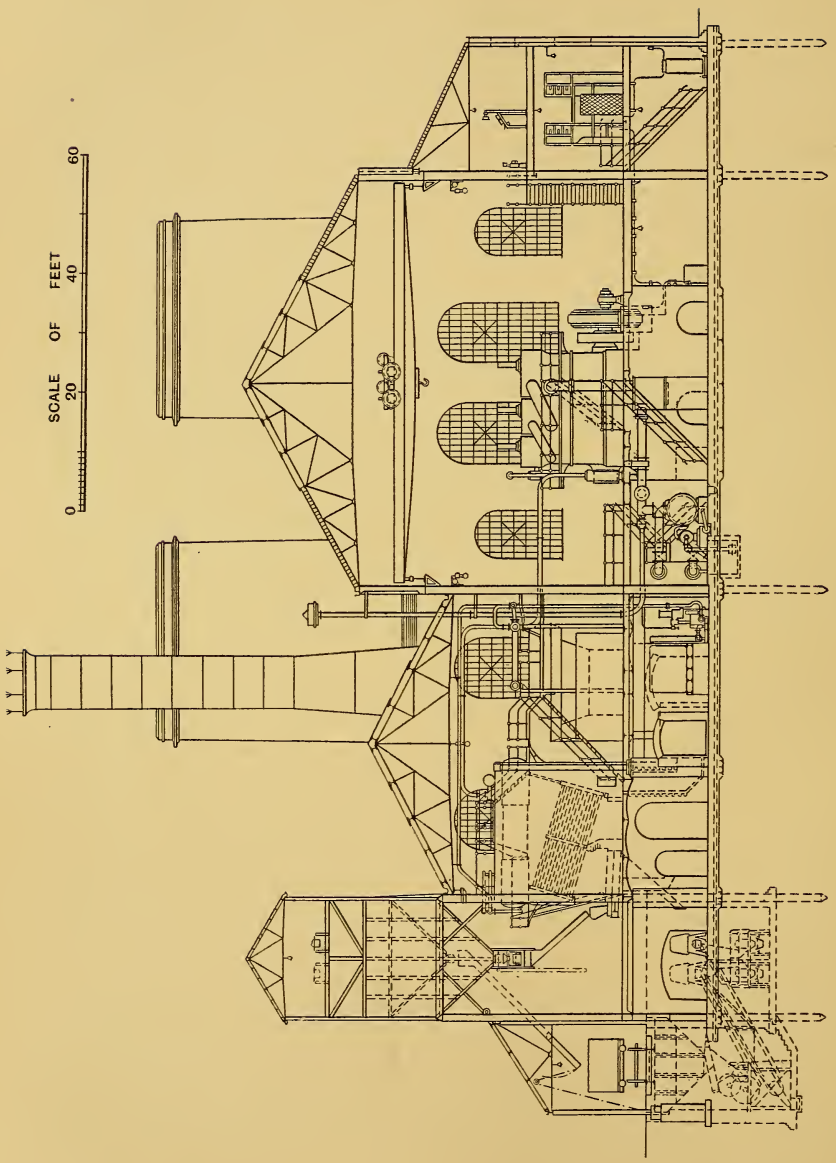


FIG. 29.

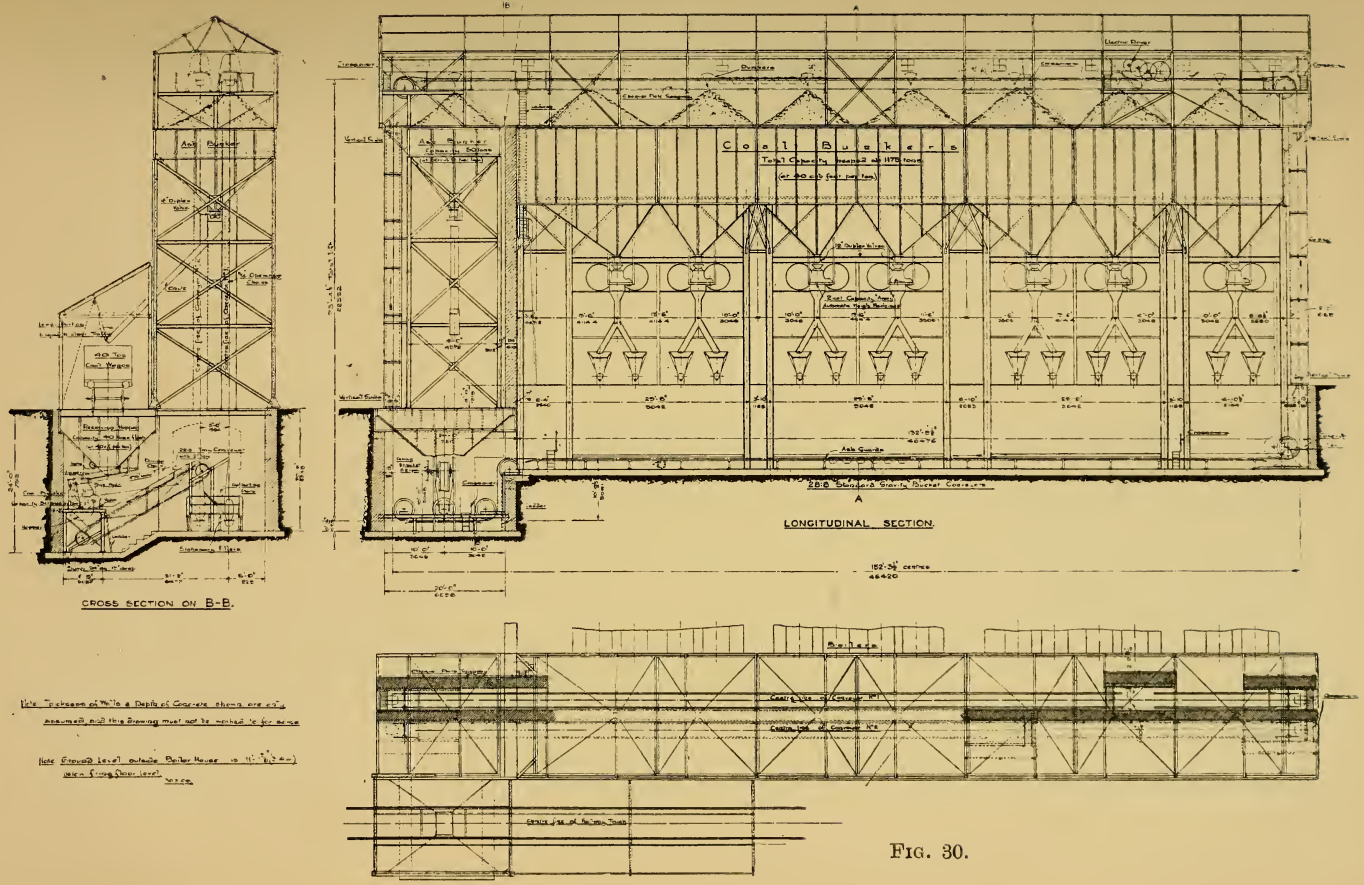


FIG. 30.

In ordinary cases it will be found that a 7 days' supply per boiler is sufficient. The bunkers can be arranged, one to each boiler, and should be designed for the above-mentioned supply on the basis of 40 cubic feet per ton. It will be found to be cheaper to build the bunkers as a continuous structure with bulkheads (which also act as stiffeners) than to build separate bunkers; Figs. 29 and 30 show the arrangements of the overhead bunkers at the Bahia Blanca power house. These, of course, have self-trimming bottoms with mouthpieces to which are attached automatic weighers recording in kilogrammes, and also in tons by the simple addition of a fixed weight so as to alter the calibration of the dials. Hinged chutes guide the coal from the bunkers to the stoker hoppers.

Safety Devices for Conveyors.—In arranging the conveyors it should always be possible to shut down the conveyor motors from several points along the conveyor route, and safety pushes actuating the motor control switch should be fixed for this purpose. A pawl is always arranged to engage between the links of the chains to prevent the conveyor from running backwards when the motor stops. A further device may be adopted as arranged by Messrs. Spencer & Co., Ltd., of Melksham, England, to prevent the buckets and chains from falling in the event of breakage. Two continuous vertical runners are fixed as shown in Fig. 31. Should the chain break it would only fall a few inches, as it would jam in the runners. A compensating carriage to take up the slack in the conveyor is always provided.

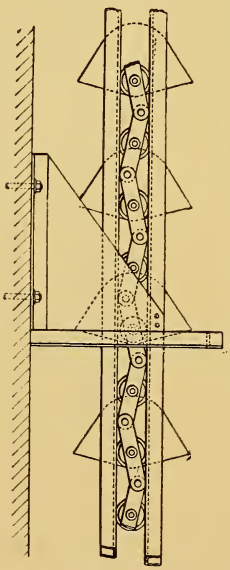


Fig. 31.

Large bunkers should also be served with a hydrant system, so that water may be available in the event of fire breaking out in any compartment. A water service is unnecessary in small bunkers, which can more readily be emptied, and in which no coal remains for any length of time.

Economy of Coal-handling Plant.—Coal-handling plant is almost generally used in large power stations, as where the

cost of labour is the same as obtains in England, the cost of mechanical handling is only $\frac{1}{5}$ that of hand firing; but in districts where native labour is cheap the cost may sometimes be saved. The Steam Users' Association of New England states that one man can fire from 0·35 to 0·43 ton per hour at an *average* cost of 2*s.* or 48 cents per ton. This, however, does not include any cost of unloading, trimming or further handling of the coal between the point of discharge and the firing floor.

Specification of Materials.—The following general specification for the structural work of bunkers will be useful to the designer.

The overhead bunkers to be made of sheet steel to hold some determined quantity of coal (usually a week's supply per boiler), based on a coal measurement of 40 cubic feet per ton.

The steel plates are usually $\frac{3}{8}$ inch in thickness, with angles and tee-bar stiffeners where necessary, shaped to suit the self-trimming angle of the particular coal, and terminating in hopper mouths fixed to the duplex cut-off valves.

All steel used to satisfy the following specification :—

Tensile strength, 26–30 tons per square inch.

Elongation not to be less than 20 per cent. in a test length of 8 inches.

The maximum working stress on any part of the bunker steel-work when fully loaded should not exceed 6 tons per square inch.

Transverse steel bracings and conveyor track and platform supports as well as the necessary conveyor housing and roof to be specified.

Adequate subdivision of the bunkers is necessary, as well as means for ascertaining the temperature of any stratum of the coal stored in them.

Coal-weighing machines are supplied, usually of 2 cwt. capacity, complete with valves, operating gear, and recording counters registering each 2 cwt. charge.

The continuous weighing machine known as the Blake-Denison, shown in Fig. 32, can be applied to any form of conveyor, the weigher adjusting itself to any variation of load or speed with an accuracy within $\frac{1}{2}$ per cent. of the true load. This machine is self-recording, the net weights passed over it being read at any time. If 20 feet of the conveyor be taken as the weighing length,

the machine registers every time a 20-foot length of conveyor passes, the weigher being driven by the conveyor itself.

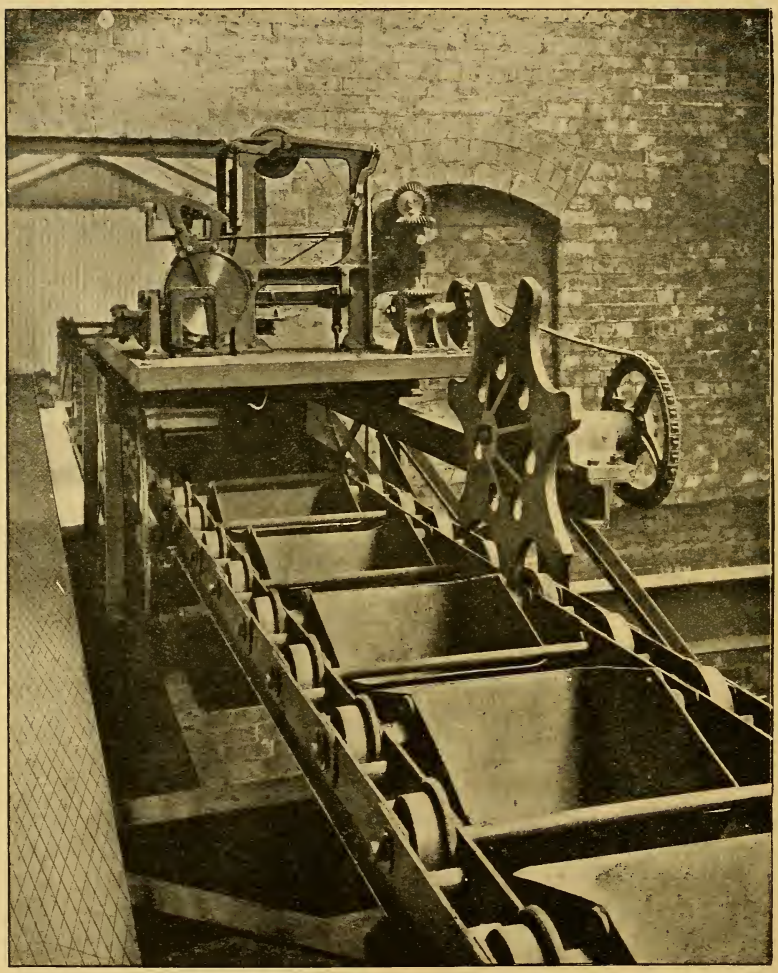


FIG. 32.

Gravity spouts to the stoker hoppers are usually of $\frac{3}{16}$-inch steel plate, counterweighted and swivelled so as to be swung out of the way.

Ash bunkers are preferably made of reinforced concrete, owing to the corrosive action of the slaked ashes, and are usually based on a measurement of 50 cubic feet to the ton.

Overhead coal bunkers, complete with all accessories, run out about £2 per ton full capacity of coal storage.

In some localities the expense of coal silos can be avoided by dumping the coal on a paved ground and then controlled and distributed by a transporter acting radially or running lengthwise, which not only unloads and trims the coal, but also picks up and discharges the coal into the regular conveyor. Such a transporter is shown in Fig. 33. In very hot and moist climates it may be necessary to build underground storage bunkers, so as to obtain a more equable all-year-round temperature.

Disposal of Ashes.—Owing to the large quantities of ashes handled in large power stations, it is practically necessary to fix mechanical plant and special appliance to deal with this. The main coal conveyors are arranged to return through the ash gallery, as shown in Fig. 30, and convey the ashes and clinker to a conveniently placed ash bunker, which in turn empties into coal waggons or barges, as the case may be, and is removed by them. The removal of ashes may sometimes prove to entail a heavy annual expenditure, and it will pay to arrange screens to subdivide the refuse, part of which can then be disposed of to builders and contractors at a price which in certain districts will be found to neutralize the cost of ash removal.

Feed Water.—In modern power houses it is almost general to use condensers; with turbines, of course, they are indispensable. Thus the only fresh feed water required is the "make-up" addition to the air-pump discharge to the hot well. Most waters will require some chemical treatment, and the air-pump discharge (in reciprocating engine power houses) will require some form of oil extractor. Both forms of apparatus may properly be included under this section.

Taking first the feed water itself. This may be obtained either from the public supply, or from a well on the power house site, or from the river on the bank of which the power house is placed.

Such waters may contain acidic properties, less frequently and more usually the soluble salts of calcium and magnesium,

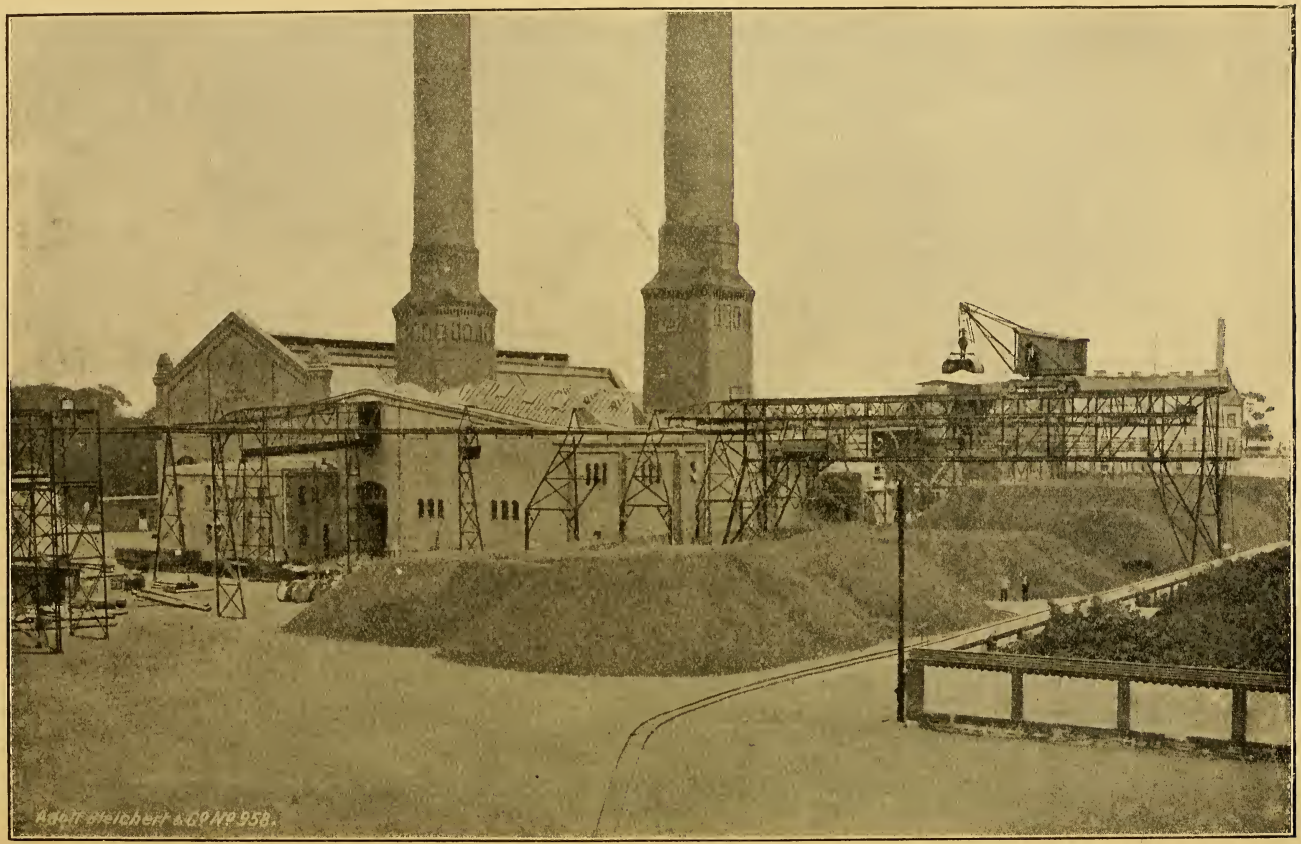


Fig. 33.

especially in deep-seated wells, or there may be vegetable acids present when water is obtained from a peaty or marshy source.

The acidic ingredients cause corrosion and pitting of the boiler plates and tubes, and electro-chemical action between the gun-metal fittings and the steel seatings, and such waters, though curable, are to be avoided. The more usual scale-forming ingredients may be removed by various means. The carbonates are usually reducible by cold treatment; but the sulphates are more refractory, and become insoluble only at a temperature of 300° Fahr. or more. One principle must be observed, that is, to precipitate as much as possible of the scale-forming matters in solution and suspension before the water enters the boilers. Approximately 10 to 15 per cent. better evaporation per pound of coal will be obtained in a clean boiler as against one with a small scale deposit, and the saving in cleaning and repairs is very appreciable, besides obtaining an increased boiler life.

Water Softening.—Scale $\frac{1}{64}$ inch in thickness causes a loss of some 2 per cent. of the fuel burnt; $\frac{1}{32}$ inch, 4 per cent.; and $\frac{1}{16}$ inch, 9 or 10 per cent. Feed waters may be described as hard or soft, according to their behaviour with soap. Hard water contains lime and magnesia salts which decompose soap to form calcium or magnesium stearates, so that in a soap test, before a lather can be obtained, the whole of the lime and magnesia salts present in solution must be converted into insoluble stearates. Boiling partially softens the water by driving out the carbonic acid gas and causing precipitation of the carbonates of calcium and magnesium. The sulphates often to be found in certain waters can only be expelled by chemical means or by raising the water to a high temperature. Lime salts are more soluble in cold than in hot water, and most are deposited at a temperature of about 300° Fahr.

The following table gives the solubilities of scale-forming materials:—

TABLE XXVI.

	Soluble in parts of pure water at 320° Fahr.	Soluble in parts of pure water at 212° Fahr.	Insoluble in water at (Fahr.).
Carbonate of lime	62,500	62,500	302°
Sulphate of lime	500	460	302°
Carbonate of magnesia	5,500	9,600	—
Phosphate of lime	—	—	212°

Exhaust Steam Heaters.—It is a barbarous practice to reduce the thermal efficiency of the boilers and run the risk of pitting and corrosion by the introduction of alkaline reagents in the boiler itself, and in land practice such an out-of-date method can and should be avoided. Feed-water heaters are sometimes introduced, through which the exhaust steam from the feed pumps and other auxiliaries is made to pass, which thus raises the feed water to a temperature approaching boiling point, expels the carbonic acid gas absorbed by the water, and by the aid of reagents extracts all solids from the feed water. Where the water contains a comparatively large proportion of magnesic or calcic sulphates such a heater is probably advisable. Where, however, the water contains only carbonates, it may be treated by a cold process. The reagents usually required (according to the analysis of the particular water) are either milk of lime with caustic soda, soda ash, fluoride of soda, or aluminate of soda.

Water Softeners.—There are many systems which have their peculiar advantages in the detail of the apparatus, but the Author's experience of several kinds leads him to suggest that the type involving a simple reagent tank and a larger precipitation tank with a steam injector and ejector, the one for "boiling" the reagents introduced, and the other for taking up the reagents so mixed and injecting them into the water to be treated, is the simplest and least expensive to maintain. Where large and somewhat complicated precipitation tanks are used, the additional difficulties of cleaning, and the cost of repair, become a nuisance in a power house, where simplicity and ease of examination and repair should be made axiomatic. The designer will, of course, ascertain whether water is obtainable on the site from an artesian well, or from a well from which the water has to be pumped. In any case, whether this be so or not, whatever the source, an analysis of the water must be taken. If from a river, then analysis at ordinary flow, drought, and storm freshets should be made. According to this analysis he will know whether to adopt a simple cold water treatment or whether a hot treatment will be necessary.

The location of this apparatus should be either in the boiler house or boiler-house basement, or in the pump-room annexe.

Capital Cost of Water-softening Plant.—The cost of water-softening plant is approximately as follows (load factor of 25 per cent.):—

TABLE XXVII.

	Per K.W. installed.	
	Hot process.	Cold process.
	£	£
Power house of 1,000 K.W. . . .	0·18	0·195
,, ,, 2,000 ,, ...	0·145	0·160
,, ,, 5,000 ,, ...	0·100	0·114
,, ,, 10,000 ,, ...	0·082	0·089
,, ,, 20,000 ,, ...	0·064	0·073

The cost of treatment obviously varies with the class of water; but, speaking in general terms, in the Author's experience a moderately hard water will be softened to 5 per cent. by Clark's scale (*i.e.* one degree of hardness represents one grain of calcium carbonate per gallon) for 0·6*d.* (1.25 cents) per 1000 gallons treated.

Since the feed "make up" to cover leakages, blow down, drains, etc., in a condensing power house may approximately be taken as 10 per cent. of the water evaporated, it is thus easy to estimate for any given power house what will be the annual cost.

Oil Elimination Plant.—As stated above, another auxiliary must be adopted in reciprocating engine equipments, viz. a chemical precipitant for the oil brought over by the exhaust steam. Incidentally, it should be mentioned that much of this should be extracted between the engine exhaust and the surface condenser by a separator, so as to avoid clogging or impairing the value of the condenser tubes. The water then discharged by the condenser wet pump is led into a mixing tank, part being shunted into a reagent tank, which can be kept charged with a mixture of chemicals of a fixed strength. The proportion of water shunted into the reagent tank causes an equal displacement of reagents, which are thus automatically adjusted to the flow of water at any time from the condenser pump. The reagent (alumino-ferric and soda ash) causes the oil in the water to become coagulated or jelly-like, and by passing this through suitable filter tanks containing wood, wool, or quartz sand, the oil is precipitated, and the resultant

water is quite pure and ready for use again in the boilers. It is, in fact, pure distilled water.

In the Davis-Perrett oil elimination plant no chemicals whatever are used, but electricity is employed to effect the separation of the oil from the water.

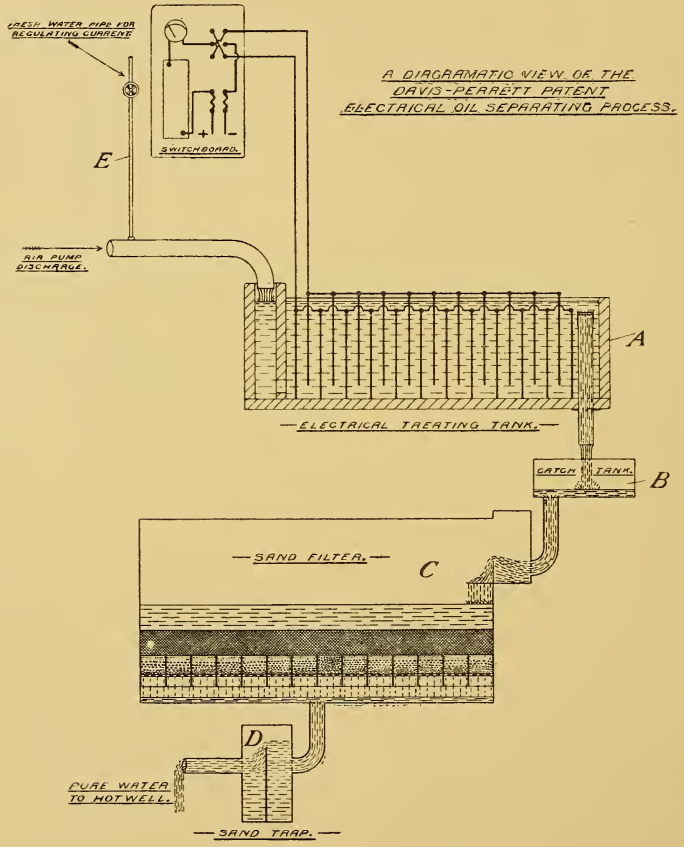


Fig. 34.

The air-pump discharge is delivered into a wooden treating tank, provided with a separate compartment into which the oily water first flows. The water then leaves this compartment and flows through other compartments of the tank, in which metallic electrodes are placed. These are arranged so as to cause the

water to circulate between them in a circuitous path. During its passage the water is subject to the action of an electric current, so that the emulsive character of the oily water is completely destroyed, and the oil forms a flocculent precipitate which is easily removed by a sand filter (see Fig. 34).

The plates in the treating tank are kept clean by a change-over switch, actuated about once in 24 hours. When the plates on one pole become foul the reversal of the current causes the oil to leave the plates and to rise to the surface as a scum.

In order to regulate the amount of current proportionately to the quantity of water required to be treated, a small quantity of tap water is allowed to flow into the treating tank with the oily water, which has the effect of altering the ohmic resistance of the solution in the treating tank.

The apparatus is usually designed so that the tanks take one unit per thousand gallons of water treated. The feed water can be treated at as high a temperature as desired, viz. 130° to 140° Fahr. or even higher. It is advisable in every case that the temperature should not be below 100° Fahr. for the sake of economy.

The purity of the water after treatment is found to be such that less than 0·1 of a grain of oil per gallon of water remains.

Table XXVIII. gives the floor space and head room occupied by apparatus of various capacities, with approximate prices.

TABLE XXVIII.

Gallons per hour.	Floor space in square feet.	Height from floor level. Feet.
1000	20	15
2000	40	15
4000	80	16
5000	100	20

The approximate price of the plant is from £150 to £100 per 1000 gallons treated per hour.

Cost of Oil Elimination Plant.—The cost of the ordinary chemical apparatus per 1000 gallons treated is as follows (load factor of 25 per cent.) :—

TABLE XXIX.

		£	
Power house of	1,000 K.W.	0·15	per K.W
,, ,,	2,500 ,,	0·102	,,
,, ,,	5,000 ,,	0·086	,,
,, ,,	10,000 ,,	0·078	,,

The apparatus is, of course, not required with turbines.

The cost of de-oiling treatment may be approximately taken at $\frac{1}{4}d.$ (0·52 cent) per 1000 gallons treated.

Apparatus to Test Hardness of Water.—A hardness testing apparatus is a necessary part of the testing equipment. This is a very simple affair, merely consisting of a burette calibrated in cubic centimetres, and some bottles of soap solution. A definite quantity of the water to be treated having been introduced into the burette, a quantity of soap solution is added and the tube shaken until a permanent lather is obtained, when the proportion of added solution, on comparison with a well-known table, will give the hardness of the water by Clark's scale.

There are other methods of testing the hardness of water, one of which is by an electrical resistance method, as designed by Mr. W. P. Digby, which has been found accurate within 1 per cent. and is extremely simple in its operation.

Economy of Feed-water Heating.—A great thermal advantage is obtained from heating feed water. If the boiler pressure is 180 lbs., then the temperature will be 379° Fahr., and if the temperature of feed water is 60° Fahr., then 319 heat units per pound of water must be added to raise it to the steam temperature. 1168 heat units are required to evaporate 1 lb. of water at 60° to steam at 180 lbs. gauge pressure. So that by heating the water to 379° a gain of 27 per cent. would be effected. The water cannot be raised practically to this temperature, but by exhaust steam heaters in small non-condensing plants the temperature may be raised to about 200°, giving a gain of some 12 per cent., and in condensing stations with economisers a temperature of 280° may be reached, thus giving a gain of about 18½ per cent.

The following Table, No. XXX., can be used as a reference to find the percentage saving through heating feed water; the boiler pressure being taken at 160 lbs. by gauge.

TABLE XXX.

Initial temperature in degrees F. of feed water.	Final temperature of feed water in degrees F.					Initial temperature of feed water in degrees C.
	160°	180°	200°	250°	300°	
50	9·34	11·04	12·74	16·99	21·24	10
55	8·96	10·66	12·37	16·64	20·90	12·8
60	8·57	10·28	11·99	16·28	20·56	15·6
65	8·17	9·90	11·62	15·92	20·22	18·3
70	7·78	9·51	11·23	15·56	19·88	21·1
75	7·38	9·11	10·85	15·18	19·53	23·9
80	6·97	8·71	10·46	14·82	19·18	26·7

Economisers.—Economisers are useful auxiliaries in a power house to obtain maximum thermal efficiencies. The exit gases from the boilers in an economically arranged boiler range have a temperature of from 425° Fahr. to 500° Fahr., usually approaching the latter figure. In smaller stations employing natural draught, an economiser is not of such material value unless the gases on leaving the boilers incline to the higher limit of temperature. Where, however, as is more usual in larger power houses, artificial draught is provided, then the fullest use of the heat can only be made by inserting economisers between the boilers and shaft with corresponding economy. The heat transmission through economiser tubes per square foot is about 2·7 to 3 B.Th.U. per degree difference between the mean temperature of the water in the economiser and that of the gases outside the tubes. An economiser is usually made up of vertical water tubes with connecting end boxes and inserted in the flue. The tubes are provided with automatic scrapers to prevent deposits of soot. The type known as Green's economiser contains all the essentials of an excellent design, embodies the automatic tube-scraping process, and is so made as to afford easy access to the tubes for inspection and cleaning and for the cutting out of old and fitting new tubes. The tubes of this economiser are always arranged in "nests." Expansion bends connect the adjacent nests of tubes, and safety valves and blow-down or sludge valves are also fitted.

The inlet feed water should always be admitted at a temperature not less than 90° Fahr., to prevent sweating in the first rows

of tubes and their consequent corrosion. This is easily arranged in condensing stations, since the hot-well water can always be expected to give a temperature of over 100° Fahr.; or some 90° Fahr. after the treatment for elimination of oil in the special apparatus for that purpose. In the rarer cases of non-condensing plants the temperature should be raised by exhaust feed heaters, in which the steam from the main engines and auxiliaries—or from some of them—is led through suitably arranged feed-water heaters.

Size of Economisers.—The following rules for the determination of economiser sizes should be followed:—

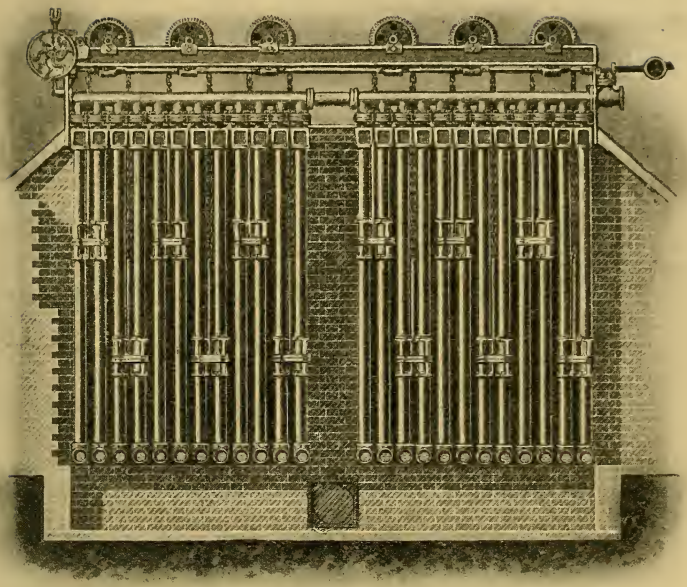
(*a*) The capacity of the economiser should be such that the feed water pumped through should be changed once in every hour. In the Green's economiser the standard capacity of each tube is $6\frac{1}{4}$ gallons, so that the number of tubes may be determined by dividing the rated evaporation of the boilers in gallons per hour by $6\frac{1}{4}$.

(*b*) On account of the scraper gearing details the number of tubes must be increased or decreased by not less than four sections, *e.g.* if the economiser is six tubes in width, the alteration of size must be twenty-four tubes per section, or if ten tubes in width, then the steps must be forty tubes per section.

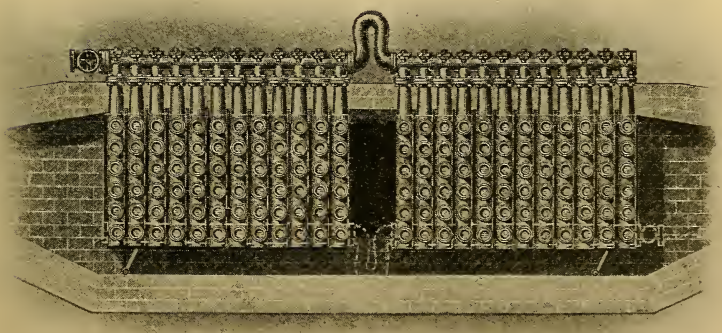
(*c*) In arranging an economiser setting, care must be exercised to provide a sufficient area of flue, and in the disposition of the tubes, so as not unduly to throttle the gases on the one hand, and to enable a sufficient time to elapse for the flow of the gases past the tubes on the other hand, so as to extract sufficient heat units and to raise the feed water to a reasonable temperature.

(*d*) The economiser must be set up so as to allow a space (usually 2 feet 6 inches in depth) underneath the lower boxes for the accumulation of soot. Soot doors are arranged at the sides of the brickwork setting for the withdrawal of this soot. Proper access must be allowed beside the economiser for the insertion of rakes to enable the soot to be withdrawn and for barrows.

The internal linings are, of course, of firebrick bonded into the stockwork, as described in the paragraph on flues, and the end covers are usually of fire lumps, or quarles, carried on light angle irons or tees, as shown in Fig. 35. Deflectors are fitted at intervals



Elevation.



Plan.

FIG. 35.

to control the direction of the gases to the best advantage and to prevent short-circuiting the gases through the side alleys.

Control dampers are arranged at both ends of every economiser setting, so as to isolate the economiser from the flue.

Large economisers are occasionally subdivided by a firebrick mid-feather, thus enabling one half to be in use while the other is under examination or being cleaned out. To save space, economisers are usually fixed above the main bye-pass flue, and it is important that the arrangement be such that the gases on leaving the boilers should enter and leave the economiser for the shaft in a continual upward tendency and not up and down or in a tortuous passage to the shaft as is sometimes found to be the case. In the Greenwich power house, for example, Plate I., the economisers are fixed on a platform above the boilers. Such an arrangement reduces the width of the boiler house, and as the path of the gases is always upwards to the chimney it is an efficient system to adopt.

Cost of Economisers.—The cost of economisers erected complete but without brickwork is approximately £0·28 per K.W. of plant served, or £14 per 1000 lbs. normal evaporation of boilers.

The usual accompaniment of tools and spares for an economiser outfit is as follows:—

Economiser Spares.—Spare tubes: spare top and bottom boxes: spare parts for scraper gear, scrapers and chains: spare lids for tubes, and a complete outfit for removal of tubes; every economiser must be provided with a pressure gauge, thermometer and pockets for the measurement of the inlet and outlet feed-water temperature, and suitable tubes let into the brickwork for the insertion of pyrometers to measure the gas temperature before entering and after leaving the economiser.

Interchangeability of similar parts should always be insisted upon.

The following Table, No. XXXI., gives the sizes, etc., of economisers:—

TABLE XXXI.

Fuel Economiser (Sizes and Capacities).

Number of tubes.	Number of tubes in width.	Number of sections.	Length of economiser.	Height over		Dimensions inside walls.			Free area for gases between tubes.			Capacity in pounds of water.	External heating surface.
				Clearing.	Sections.	Without deflectors.	With deflectors at back.	With deflectors back and front.	Without deflectors.	With deflectors at back.	With deflectors back and front.		
			ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	sq. ft.	sq. ft.	sq. ft.	lbs.	sq. ft.
96	6	16	9 8	23 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	6,000	960
120	6	20	12 1	23 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	7,500	1,200
144	6	24	14 6	23 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	9,000	1,440
168	6	28	16 11	23 6	10 2¼	4 8	5 5	—	21·5	28·5	36·25	10,500	1,680
192	6	32	19 4	23 6	10 2¼	4 8	5 5	6 4	21·5	28·5	36·25	12,000	1,920
216	6	36	21 9	23 6	10 2¼	4 8	5 5	6 4	21·5	28·5	36·25	13,500	2,160
240	6	40	24 2	23 6	10 2¼	4 8	5 5	6 4	21·5	28·5	36·25	15,000	2,400
64	8	8	4 10	23 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	4,000	640
96	8	12	7 3	23 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	6,000	960
128	8	16	9 8	23 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	8,000	1,280
160	8	20	12 1	23 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	10,000	1,600
192	8	24	14 6	23 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	12,000	1,920
224	8	28	16 11	23 6	10 2¼	6 0	6 9	—	26·5	33·5	41·25	14,000	2,240
256	8	32	19 4	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	16,000	2,560
288	8	36	21 9	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	18,000	2,880
320	8	40	24 2	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	20,000	3,200
352	8	44	26 7	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	22,000	3,520
384	8	48	29 0	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	24,000	3,840
416	8	52	31 5	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	26,000	4,160
448	8	56	33 10	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	28,000	4,480
480	8	60	36 3	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	38,000	4,800
512	8	64	38 8	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	32,000	5,120
544	8	68	41 1	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	34,000	5,440
576	8	72	43 6	23 6	10 2¼	6 0	6 9	7 8	26·5	33·5	41·25	36,000	5,760
80	10	8	4 10	23 6	10 2¼	7 4	8 1	—	31·5	38·25	46·5	5,000	800
120	10	12	7 3	23 6	10 2¼	7 4	8 1	—	31·5	38·25	46·5	7,500	1,200
160	10	16	9 8	23 6	10 2¼	7 4	8 1	—	31·5	38·25	46·5	10,000	1,600
200	10	20	12 1	23 6	10 2¼	7 4	8 1	—	31·5	38·25	46·5	12,500	2,000
240	10	24	14 6	23 6	10 2¼	7 4	8 1	—	31·5	38·25	46·5	15,000	2,400
280	10	28	16 11	23 6	10 2¼	7 4	8 1	—	31·5	38·25	46·5	17,500	2,800
320	10	32	19 4	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	20,000	3,200
360	10	36	21 9	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	22,500	3,600
400	10	40	24 2	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	25,000	4,000
440	10	44	26 7	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	27,500	4,400
480	10	48	29 0	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	30,000	4,800
520	10	52	31 5	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	32,500	5,200
560	10	56	33 10	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	35,000	5,600
600	10	60	36 3	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	37,500	6,000
640	10	64	38 8	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	40,000	6,400
680	10	68	41 1	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	42,500	6,800
720	10	72	43 6	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	45,000	7,200
760	10	76	45 11	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	47,500	7,600
800	10	80	48 4	23 6	10 2¼	7 4	8 1	9 0	31·5	38·25	46·5	50,000	8,000

Feed Pumps may either be motor- or steam-driven. In a large power house there is much to be said for a combination of both types. The Author, however, inclines to the use of steam-feed pumps alone because (*a*) they are less expensive in capital cost than the motor-driven pumps; (*b*) the commercial efficiency of the modern high-class pump is very high; (*c*) they are more easily regulated over wide ranges of delivery.

A large high-class compound pump will easily deliver 110 lbs. of feed water per lb. of steam against the boiler pressure through a moderate and well-designed feed-water pipe system. In other words, a steam-feed pump requires something less than 1 per cent. of the steam raised to deliver the necessary amount of feed water. Simple steam pumps will deliver some 75 to 85 lbs. of feed water per lb. of steam used. There is also something to be said for keeping the boiler-house system intact and independent of the electrical system in the event of any interruption of supply. Of course, electrical pumps can be supplied from the independent exciters where these are used, and the more reliably in cases where there is also an auxiliary battery. Where steam-feed pumps are adopted they should always be supplied from a donkey steam pipe, so that the pumps can be supplied independently of the main-steam range. Both a duplicate steam and duplicate feed suction and delivery are indispensable.

Details of Feed Pumps.—Fig. 36 shows a typical steam-feed pump. The following practical hints may be adopted with advantage:—

(*a*) The water end should always be brass lined with solid gun-metal plunger, and bucket rod of phosphor bronze. If cast-iron plungers are used the rings should be gun-metal if used with hot water, and ebonite if used with cold feed.

(*b*) The valves and seatings are, of course, always brass or brass with specially hard facings, to reduce attrition and wear, and must be easily accessible and the seat rings readily renewable.

(*c*) The piston speed at full duty should not exceed 30 feet per minute.

(*d*) In compound-tandem pumps the H.P. cylinder should always be separated from the L.P. cylinder, so as to give access to the glands for packing and examination. In cases where the

H.P. sits immediately on the L.P. cover with inaccessible stuffing box, there is sometimes a leakage of H.P. steam into the L.P. cylinder.

(*e*) A separate multiple sight-feed lubricator should be fixed instead of grease cups, and thus ensure a uniform oil supply without the extravagance and wasteful flushing where cups are used.

(*f*) The pump duty when supplied at a specified steam pressure should never be less than 110 lbs. of water delivered against the boiler pressure for each lb. of steam applied to the pump (see Appendix V.).

(*g*) The stroke should be adjustable while the pump is working, and the pump should start instantly at any point of its stroke.

Air vessels are provided on the suction as well as the delivery, and snifting cocks should always be fitted for the admission and control of air. Steam-feed pumps should be supplied with a drip tray on which each should stand to preserve cleanliness, and relief valves in each cylinder and on the pump deliveries. An automatic stroke counter should be fitted to the valve gear. The following Table, No. XXXII., gives the particulars of various standard sizes of pumps, and is supplied by the courtesy of Messrs. J. P. Hall & Sons, Peterborough, England.

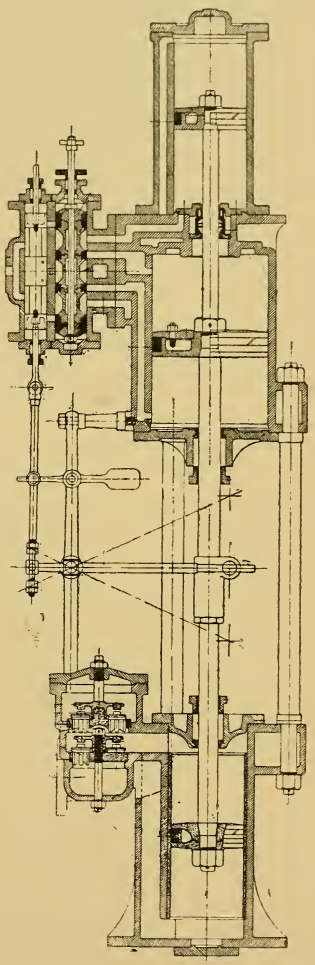


FIG. 36.

The approximate cost of steam-feed pumps may be taken at £40 per 1000 gallons capacity per hour, or £0·06 per K.W. of plant installed.

Electrical pumps are usually of the three-throw pattern. Fig. 37 shows a typical Edwards' single-acting pump. This type of

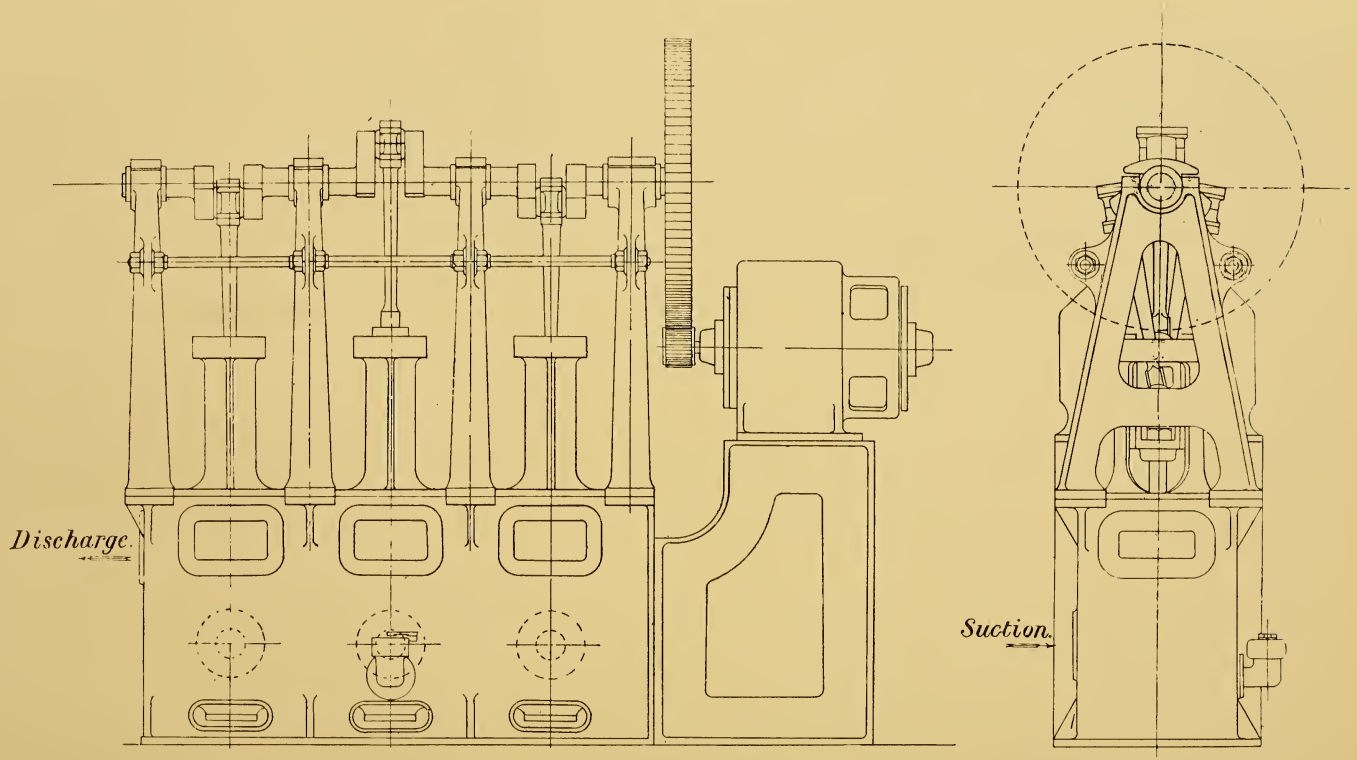


FIG. 37.

pump, while costing more initially, is very efficient in working; a duty of 1000 lbs. of water can be given with an input of 240 watts.

TABLE XXXII.

STANDARD SIZES OF COMPOUND STEAM FEED PUMPS.

Diameter (inches).			Length of stroke (inches).	No. of strokes per minute.	Duty gallons per hour.	Diameter of pipes (inches).				Floor space.	Height.	Total weight.
H.P. cylinder.	L.P. cylinder.	Pump.				Steam.	Exhaust.	Suction.	Discharge.			
										ft. in. ft. in.	ft. in.	tons.
6¼	9½	6¼	12	14	2,200	1	1¼	3	2½	2 0 × 2 0	6 10	0·60
6¼	9½	6¼	15	14	2,600	1	1¼	3	2½	2 0 × 2 0	7 10	0·65
7½	12	7½	12	14	3,000	1	1½	3½	3	2 4 × 2 4	7 0	0·775
7½	12	7½	15	14	3,800	1	1½	3½	3	2 4 × 2 4	8 1	0·8375
9	13¾	8½	15	13	4,500	1¼	1¾	4	3½	2 8 × 2 8	7 7	1·2125
9	13¾	8½	18	12	5,000	1¼	1¾	4	3½	2 8 × 2 8	8 4	1·3375
9	13¾	8½	21	12	6,000	1¼	1¾	4	3½	2 8 × 2 8	9 1	1·475
9¾	15¼	9¾	18	12	7,000	1¼	2	4½	4	3 0 × 3 0	8 6	1·500
9¾	15¼	9¾	21	12	8,000	1¼	2	4½	4	3 0 × 3 0	9 3	1·65
11	18	10½	24	12	10,000	1½	2¼	6	6	3 4 × 3 4	10 4	2·45
12¼	20	11¾	24	12	12,500	1¾	2¼	6	6	3 6 × 3 6	10 4	2·7

Table No. XXXIII. sets out the particulars of standard sizes of electrically driven three-throw pumps.

TABLE XXXIII.

STANDARD LIST OF ELECTRICALLY-DRIVEN TRIPLEX BOILER FEED PUMPS.

Suitable for a boiler pressure of 180 lbs. per square inch, and plunger speed at full load not exceeding 70 feet per minute. Each pump provided with a double reduction machine cut gear, cast-iron base for motor, raw hide pinion, delivery air vessel, bye-pass and relief valve on delivery pipe.

Duty in gallons per hour.	Sizes and particulars of pumps.								Motors.	
	Diameter of plungers.	Stroke	Revs. per min.	Diam. suction pipe	Diam. delivery pipe.	Including above accessories, packing for shipment, and delivery F.O.B. London.				
						Weight.	Price iron fitted.	Extra for gun-metal fitting.	Min. B.H.P.	Approx. R.P.M.
	ins.	ins.		ins.	ins.	lbs.	£	£		
1,000	3	6	39	3	2½	2,700	65	6	3·2	800
2,000	4	6	43	3	2½	3,400	76	7	6·4	800
3,000	4½	8	39	3	2½	3,900	93	9·5	9·6	800
4,000	5	8	42	4	3	5,400	121	10·75	12·2	800
5,000	5½	8	43	4	3	8,100	157	11·75	15·2	800
6,000	6	8	43½	5	4	8,600	167	12·75	18·2	700
7,000	6½	8	43	5	4	8,900	172	14·5	21·2	700
8,000	6½	10	39	5	4	10,200	215	16	24·2	700
9,000	7	10	38	5	5	10,600	222	19·25	27·2	600
10,000	7½	10	37	6	5	13,400	270	22·25	30·4	600

SIZE OF ELECTRICAL TRIPLEX PUMPS.

Duty in gallons per hour.	Length. ft. ins.	Width. ft. ins.	Height. ft. ins.
1,000	5 0	4 3	3 3
2,000	5 0	4 9	3 9
3,000	6 3	5 7	4 3
4,000	6 3	5 7	4 3
5,000	6 6	5 7	4 6
6,000	6 6	5 9	4 6
7,000	6 9	5 9	4 9
8,000	8 9	7 5	6 3
9,000	8 9	7 5	6 3
10,000	9 0	7 5	6 6

Hot Wells should be of liberal capacity and so arranged in level with respect to the feed pumps that the water may flow to the pump barrels, and not have to be lifted. In fact, the condensed-steam discharge should be raised by small auxiliary pumps to a sufficiently high level so that the water will gravitate through any necessary oil-extracting plant to the hot well, thence through the feed-water meters to the pumps. A systematic lay-out on this principle is desirable. Hot wells should be arranged approximately $\frac{1}{20}$ of the normal boiler-range evaporation with which they are connected. It is desirable to subdivide a hot well into two compartments so as to enable valves to be examined and the tanks to be cleaned and painted. A supplementary "make-up" supply must be provided through ball floats and valves. All discharge pipes leading from the condensers should be submerged, so as to prevent the water falling through the air and thus becoming aërated. *Aëration* of feed water is a frequent cause of corrosion in boilers.

Meters.—There are several types of feed-water meters. These must be inserted on the suction side whenever possible.

The Kennedy hot-water meter is frequently used to measure boiler feed. This meter is very simple and depends on a piston, the length of travel of which in its cylinder (and the number of strokes) is the measure of the water flowing through the meter. The actuating mechanism is of the simplest description, being merely a cock-key which is always in one of two positions, leading the inlet water alternately to the bottom and top of the piston. The piston rod passing through a gland terminates in a rack, the pinion gearing into which actuates the index mechanism

through bevel wheels. A great accuracy can be obtained with these meters, since the measure of the water passing is dependent not on the strokes made by the piston, but on the length of travel. The following Table, No. XXXIV., gives the standard sizes up to 16,000 gallons per hour.

TABLE XXXIV.

Bore of inlet and outlet (inches).	Normal delivery (gallons per hour).	Maximum delivery (gallons per hour).	Weight of meter (lbs.).
$\frac{1}{2}$	400	850	168
$\frac{3}{4}$	600	1,500	224
1	1,000	2,000	294
$1\frac{1}{2}$	1,700	3,000	476
2	3,600	5,000	812
3	5,000	8,000	1176
4	10,000	15,000	2016
6	16,000	25,000	2965

The "Venturi" meter is now frequently used in power-house work, both for feed water and for circulating water systems. This meter is dependent on the law that water flowing through a pipe of diminishing area loses the pressure it exerts laterally as it gains in velocity. A "Venturi" tube inserted in any pipe consists of two truncated cones and a "throat," and within a known limit of statical pressure, a sufficiently high velocity of the water will cause it not only to lose all lateral pressure, but also to form a vacuum. Small pipes are led away from a point at the full bore of the main and also from the throat, and these can be led to a distance as great as 1000 feet from the "Venturi" tube without impairing the accuracy of the record. The pipes are led to a recorder which may be placed, if required, in the Resident Engineer's office. The recorder is generally fitted with a recording drum, and also with a counter giving the total quantity passed. The registration can also be done by electrical method if desired. The recorder consists of a mercurial U-tube connected to the full bore pipe and to the throat and thus records the "Venturi" head between the two points; and also of clockwork and gear which are controlled by the U-tube, the connection between these two

elements, pressure and time, being made by means of floats resting on the mercury in the U-tube. The "Venturi" meter is entirely independent of the temperature of the water passing. The only thing necessary in practice is to see that the throat is free from scale or deposit, which can readily be done by examination from a hand hole provided for the purpose. Where used in conjunction with boiler-feed pumps, it is advisable to use an auxiliary tank to equalize the head and serve as an accumulator as shown in Plate VI., which depicts the installation of these meters for the Bahia Blanca power house. The average price for boiler-feed water meters is £25 per 1000 gallons per hour.

Blow-down Pipes and Sumps.—Suitable steel necks are riveted to the front plates of drum-type boilers, to carry the blow-down valve. In water-tube boilers the mud drum is usually separated from the boiler proper and a blow-down pipe is connected to the drum and led to the outside of the brick casing with the blow-down valve attached at that point. In some cases the mud drum is prolonged through the side wall. This valve should always have a cast steel body with brass parts and preferably with parallel slide valve, a type which minimizes the risk of scoring through water and grit blowing through when it is supposed to be closed, with consequent loss of water and of heat units. This type of valve enables the washing out of the boiler containing bits of scale, etc., to be done with a minimum chance of damaging the valve. With corrosive waters or those containing much scale-forming material it is good practice to have a cock and valve arranged in series, the fitting nearest the boiler being always opened last and closed first. Thus the fitting farthest from the boiler never has to be shut or opened under pressure, and the valve and seat are always kept in good condition. The blow-down pipe must be laid in a trench so as to be accessible and arranged with easy bends to prevent lodgement of scale and sludge, and plenty of standard expansion bends in a long length of pipe work. The end is taken down to a suitable sump outside the power house, and is usually carried slightly below the overflow level of the sump. The sump must be of liberal dimensions, especially in cases where it discharges into public sewers, so as to allow the water to cool before it is finally discharged into the sewer. In such cases it is better to arrange a two-compartment

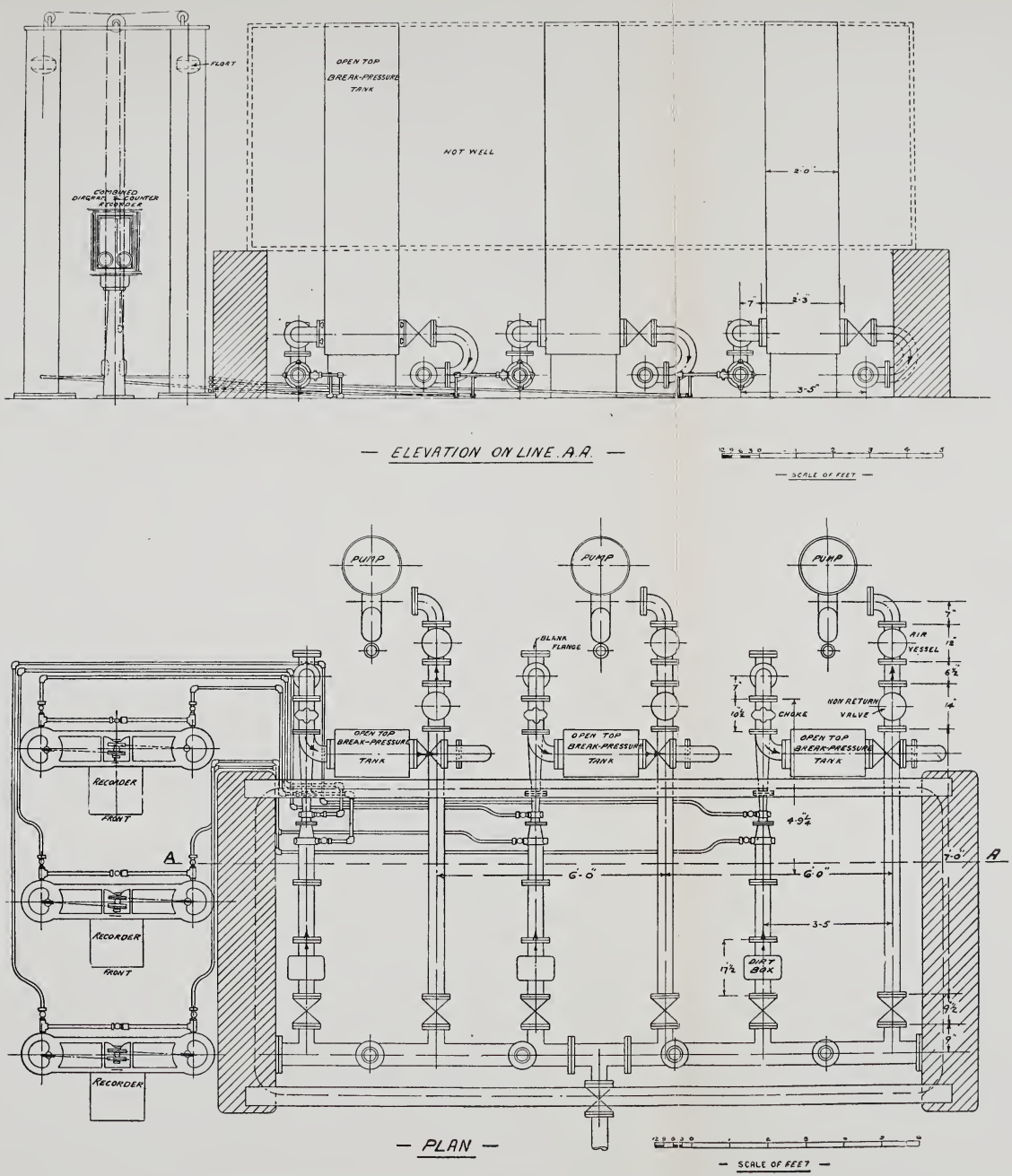


PLATE VI.—FEED PIPE SYSTEMS. LAY-OUT OF VENTURI METERS.

[*To face page* 118.

sump, into the one-half of which the blow-down pipe discharges and the other overflowing to the sewer and so arranged that the latest discharge from the hot sump displaces the standing water in the other compartment which overflows to the sewer. The sump should be covered with checker plating and fitted with an exhaust pipe carried to the eaves of the building to discharge vapour. The blow-down pipe is usually of 4 inches diameter, and the exhaust pipe is preferably 6 inches diameter, or not less than 4 inches.

CHAPTER V

STEAM AND FEED-PIPE SYSTEMS

THE principles to be aimed at in both the steam and the feed-pipe systems of any power house are (*a*) simplicity and (*b*) reliability. As the boilers are dependent upon the reliability of the water supply, so the engines or turbines are dependent on the reliability of the steam supply; each is a link in the chain between the fuel at the one end and the electrical output at the other. As has before been stated, the ideal of simplicity would be one boiler, one steam pipe, and one engine; each set a complete unit in itself and independent of its neighbours. As, however, it is not practicable either to build so large a boiler in one unit to supply the larger engines or turbines: or so to arrange matters that Boiler A can always supply Engine A, some departure from this ideal of simplicity is necessary. Firstly, in the larger power houses several boilers are necessary for the supply of each engine; secondly, cleaning, repairs to brickwork, replacement of fire bars, etc., require the periodical laying off of each boiler so that it comes about in practice that boilers A, C, D, and F, it may be, are required to supply engines A and B while boilers B and E are laid off for some reason or other. Therefore a connecting pipe or header is usual for the paralleling of the steam supply, and this is provided for in various ways according to the lay-out of the plant. Various examples of typical steam-pipe systems will now be discussed. The designer must bear in mind the following necessary or axiomatic rules.

Principles to be observed in Pipe Designs.—(*a*) The system to be as simple and direct as possible.

(*b*) The pipes to be laid consistently to agreed and recognized points of drainage, *e.g.* the engine separators.

(*c*) As few points of drainage as are consistent with safety to be incurred.

(*d*) All horizontal valves to be "full way," so as to prevent accumulation of water.

(*e*) All expansion bends to be laid in a horizontal plane, so as to avoid pockets for water.

(*f*) Elasticity to be given to the system by a sufficient number (but not too many) bends.

(*g*) A single branch from each boiler to be taken into a single header common to the boilers and engines comprising the completed unit or part of the power house.

(*h*) This header to be subdivided by valves where necessary for the proper protection of the system.

(*i*) A single branch pipe to lead from the header to the engine or turbine, or, with very large turbines, two pipes may be arranged so as to avoid very large diameters as shown in Figs. 2 and 42.

(*j*) The main header preferably to be arranged on the boiler-house side of the engine-room wall so as to be clear of chain slings, etc. Sometimes this is not possible, and the header has to be arranged within the engine-room when it may be placed above or beneath a platform to give accessibility to valves.

(*k*) All valves to be operated both from the pipe-work platform connecting with the boiler tops, etc., and also through extended spindles, from the ground level.

(*l*) All valves to be marked clearly "open" or "shut" in the language of the country in which the power house is situated, and arrowheads cast on the hand wheels to show the direction of rotation. In subsequent working labels marked "Shut" should always be attached to the valve hand-wheels when work is being carried on in any section beyond this valve and controlled by it.

(*m*) All the pipes, flanges, bends, and tees to be of the standard dimensions, preferably of those of the recognized British Engineering Standards Committee.

(*n*) The pipes to be large enough to minimize the fall of pressure between boilers and engine-top valves.

(*o*) At the same time the pipes should be as small as possible so as to reduce radiation losses—quite a factor to be considered in a big system.

(*p*) The lengths to be as great as are practicable, so as to reduce the number of joints to a practical minimum.

(*q*) The joints should be made with corrugated metal rings, and a suitable good paint, which should neither soften under water nor contract with heat, and as thin as possible. The rings should be of such diameter as to lie both within and without the bolt circle. Brass rings are used for saturated, and metal rings with superheated steam.

(*r*) The sectionizing should be such that the failure of any one pipe should affect only one engine or one boiler unit.

Specification of Materials.—Steam pipes of smaller sizes up to 12 inches diameter are now always specified to be solid drawn weldless pipes made from the best quality acid open hearth steel, having a tensile strength of from 21·6 to 29·6 tons per square inch with an elongation of 27 per cent. in a test length of 2 inches.

Pipes of larger diameter, say, from 13 inches to 16 inches diameter, are made lap-welded, the steel having a tensile strength of 22 to 26 tons per square inch with an elongation of 25 per cent. in 8 inches. Steam pipes can now be made up to 30-foot lengths according to the position of the riveted branches or valves, and this greater length reduces the number of joints. The difficulties of carriage and of erecting such lengths, however, often prevent their adoption. The branches on all pipes above 6 inches diameter are riveted on so as to reduce the number of joints in the system and to avoid the use of cast tee pieces. These branches have saddles accurately shaped to fit the curvature of the main length drilled in position and riveted up. The flanges of pipes up to and including 6-inch pipes are screwed on to the pipe, and the pipe ends are expanded and beaded into a recess on the flange faces. In the case of pipes over 6 inches diameter riveted flanges are used accurately bored and shrunk on to the pipes, and after being riveted and caulked and the ends of the pipes hammered up to the flanges, the flanges are accurately faced, turned on the edges, and machined or knifed out at the backs to give a level bearing surface for the boltheads and nuts.

Tables Nos. XXXV. and XXXVI. give the British Engineering Standard sizes of pipes, flanges, bends, and tees.

TABLE XXXV.

THIN WELDLESS STEEL STEAM PIPES (FOR STRAIGHTS).

(Steam pressure 225 lbs. per square inch.)

Internal diameter of pipe.	External diameter of pipe.	Thickness of pipe.	Flanges.				
			Diameter.	Thickness.	Diameter of bolt circle.	Diameter of bolts.	No. of bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.	
3	$3\frac{1}{2}$	$\frac{3}{16}$	8	1	$6\frac{1}{2}$	$\frac{5}{8}$	8
$3\frac{1}{2}$	4	$\frac{3}{16}$	$8\frac{1}{2}$	1	7	$\frac{5}{8}$	8
4	$4\frac{3}{8}$	$\frac{3}{16}$	9	$1\frac{1}{8}$	$7\frac{1}{2}$	$\frac{5}{8}$	8
5	$5\frac{1}{2}$	$\frac{3}{16}$	11	$1\frac{1}{4}$	$9\frac{1}{4}$	$\frac{3}{4}$	8
6	$6\frac{1}{2}$	$\frac{1}{4}$	12	$1\frac{1}{4}$	$10\frac{1}{4}$	$\frac{3}{4}$	12
7	$7\frac{5}{8}$	$\frac{1}{4}$	$13\frac{1}{4}$	$1\frac{3}{8}$	$11\frac{1}{2}$	$\frac{3}{4}$	12
8	$8\frac{5}{8}$	$\frac{1}{4}$	$14\frac{1}{2}$	$1\frac{3}{8}$	$12\frac{3}{4}$	$\frac{3}{4}$	12
9	$9\frac{3}{4}$	$\frac{5}{32}$	16	$1\frac{1}{2}$	14	$\frac{7}{8}$	12
10	$10\frac{3}{4}$	$\frac{5}{16}$	17	$1\frac{1}{2}$	15	$\frac{7}{8}$	12
12	$12\frac{3}{4}$	$\frac{3}{8}$	$19\frac{1}{4}$	$1\frac{5}{8}$	$17\frac{1}{4}$	$\frac{7}{8}$	16

TABLE XXXVI.

TEES AND BENDS.

(Steam pressure 225 lbs. per square inch.)

Internal diameter of pipe.	Centre to flange face.	Radius of centre-line of bend.
ins.	ins.	ins.
3	6	4
$3\frac{1}{2}$	$6\frac{1}{2}$	$4\frac{1}{2}$
4	7	$4\frac{3}{4}$
5	8	$5\frac{1}{2}$
6	9	$6\frac{1}{2}$
7	10	$7\frac{1}{4}$
8	11	$8\frac{1}{4}$
9	12	9
10	13	10
12	15	$11\frac{3}{4}$

All bolts and nuts (studs should not be allowed) are specified to be of soft and ductile steel, to stand bending double, both hot and cold, without showing defects. The steel should give a tensile strength of from 26 to 30 tons per square inch, with an elongation of 25 per cent. in a test length, equal to eight times the diameter of the bar. All heads, stems, threads, and nuts should be of accepted Whitworth or Engineering standard, and all nuts should

be a spanner-tight fit on their bolts. In erecting pipe work the lengths of bolts should be so selected for particular flanges that when put up in position the shank should just show through the nut.

Inspection and Testing.—Every pipe should be inspected during construction, cleaned both inside and out, and assembled and coupled together at the makers' works. This is usually done in practicable lengths so as to facilitate inspector's examination and hydraulic testing. The tubes from which the pipes are manufactured up to and including 6 inches diameter are usually tested to 1000 lbs. per square inch, and above 6 inches diameter to 600 lbs. per square inch. When the pipes have had their flanges attached and faced up, they are usually tested again by hydraulic pressure up to 350 lbs. per square inch.

In erecting pipes no springing into position should be allowed, and if well made and erected the pipes should assemble accurately. Expansion bends may be excepted: these should be so offered up that the "spring" in them when cold should equal the spring in the other direction when hot. These, therefore, must be slightly sprung into position during erection. The interiors of all pipes should be most carefully cleaned out after erection, so as to remove excess jointing cement, etc., which may collect during erection.

Steam Velocities in Pipes.—Any increase in the diameter of a pipe obviously increases its cross-sectional area at a greater rate than its circumference, since the circumference is a function of the diameter, whereas the area is a function of the square of the diameter. Thus, it is easy to choose a pipe of such size as to pass a given quantity of steam without undue fall of pressure, and, at the same time, to have the outside area of pipe small enough to keep the radiation losses as small as possible. The external surface of steam pipes is usually from 0·225 square foot to 0·24 square foot per K.W. rated output of the plant. It is usual to base steam-pipe dimensions on steam velocities of the following values, viz. :—

Saturated steam.	Pipes up to and including 3 inches diameter	75 feet per sec.
,,	Pipes above 3 inches diameter	90 ,, ,,
Superheated steam.	Pipes up to and including 9 inches diameter	120 ,, ,,
,,	Pipes above 9 inches diameter	140 ,, ,,

The fall of pressure in a well-designed pipe system between boilers and engine should not exceed $1\frac{1}{2}$ per cent. of the initial pressure. Fig. 38 shows curves giving the relation between the weight of steam passed per minute through pipes of different diameters at velocities between 3000 and 9000 feet per minute, and based on 180 lbs. gauge

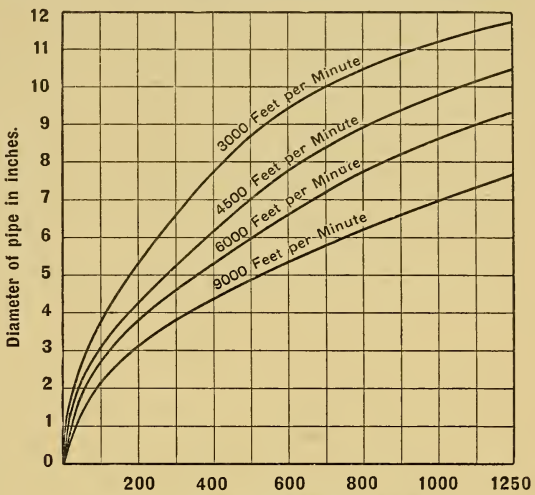


FIG. 38.—Weight of steam in lbs. per minute.

TABLE XXXVII.

Speed of saturated steam, 90 ft. per sec.		ins.	Steam quantities in lbs. per hour. Working pressure, 120 lbs. = 8·5 kg. = 8 atmospheres. Saturated steam.	Steam superheated by 100° F., 55° C.	150° F., 83° C.	200° F., 110° C.	250° F., 140° C.	300° F., 167° C.
Speed of steam.	Sat. 75 ft., superh. 100 ft. per sec.	$\frac{1}{2}$	110	130	120	110	110	100
		$\frac{3}{4}$	250	290	270	260	245	230
		1	440	510	480	460	435	410
		$1\frac{1}{4}$	690	800	750	710	680	640
		$1\frac{1}{2}$	1,000	1,150	1,080	1,020	980	930
		2	1,770	2,050	1,920	1,820	1,740	1,650
		$2\frac{1}{2}$	2,770	3,200	3,000	2,840	2,700	2,570
		3	4,000	4,600	4,300	4,100	3,900	3,700
	Speed of superh. steam, 120 ft. per sec.	$3\frac{1}{2}$	6,500	7,500	7,100	6,700	6,400	6,000
		4	8,500	9,800	9,200	8,700	8,400	7,900
		$4\frac{1}{2}$	10,800	12,500	11,700	11,000	10,600	10,000
		5	13,300	15,400	14,400	13,600	13,000	12,300
		6	19,000	22,000	20,800	19,600	18,800	17,700
		7	26,000	30,100	28,000	26,700	25,600	24,000
		8	34,000	39,400	37,000	35,000	33,400	31,500
		9	43,000	50,000	47,000	44,000	42,000	40,000
	Speed of superh. steam, 140 ft. per sec.	10	53,000	72,000	67,000	64,000	61,000	57,500
		11	64,000	87,000	81,000	77,000	74,000	70,000
		12	77,000	104,000	97,000	92,000	87,000	83,000
		13	90,000	122,000	114,000	108,000	103,000	97,000
		14	104,000	141,000	132,000	125,000	119,000	113,000
		15	120,000	162,000	150,000	143,000	137,000	130,000
		16	136,000	184,000	172,000	163,000	156,000	147,000
		17	154,000	208,000	194,000	184,000	176,000	166,000
		18	172,000	233,000	218,000	206,000	197,000	186,000
		19	192,000	260,000	243,000	230,000	220,000	208,000
		20	212,000	290,000	270,000	254,000	243,000	230,000

pressure per square inch, and Tables Nos. XXXVII., XXXVIII., and XXXIX. give the velocities in pipes for saturated and superheated steam at 120, 160, and 200 lbs. pressure respectively. In modern turbine practice a speed of 5400 feet per minute is usually adopted.

Since the density of a given volume of steam varies directly as the pressure, according to Boyle's law, any other curves for other initial pressures than the datum used for the above curves can be easily drawn.

Flow of Steam through Pipes.—Table No. XL. (page 128),

TABLE XXXVIII.

Speed of steam.			Steam quantities in lbs. per hour.					
			Working pressure, 160 lbs. = 11¼ kg. = 11 atmospheres.					
			Saturated steam.	Steam superheated by				
				100° F., 55° C.	150° F., 83° C.	200° F., 110° C.	250° F., 140° C.	300° F., 167° C.
		ins.						
Sat. 75 ft., superh. 100 ft. per sec.		¼	140	160	150	145	140	130
		½	320	370	350	330	310	290
		1	570	660	610	580	550	520
		1¼	885	1,030	960	900	870	820
		1½	1,280	1,480	1,380	1,300	1,250	1,180
		2	2,260	2,630	2,450	2,300	2,200	2,100
		2½	3,540	4,100	3,850	3,600	3,500	3,300
		3	5,100	5,900	5,500	5,200	5,000	4,700
Speed of saturated steam, 90 ft. per sec.	Speed of superh. steam, 120 ft. per sec.	3½	8,300	9,650	9,000	8,500	8,200	7,700
		4	10,900	12,600	11,800	11,000	10,700	10,000
		4½	13,800	16,000	15,000	14,000	13,500	12,700
		5	17,000	19,700	18,400	17,400	16,700	15,700
		6	24,500	28,300	26,500	25,000	24,000	22,600
		7	33,300	38,600	36,000	34,000	32,600	31,000
		8	43,500	50,000	47,000	44,500	43,000	40,000
		9	55,000	64,000	60,000	56,000	54,000	51,000
	Speed of superh. steam, 140 ft. per sec.	10	68,000	92,000	86,000	81,000	78,000	73,000
		11	82,000	110,000	104,000	99,000	94,000	89,000
		12	98,000	132,000	124,000	117,000	112,000	105,000
		13	115,000	155,000	145,000	137,000	130,000	124,000
		14	133,000	180,000	168,000	160,000	152,000	144,000
		15	153,000	207,000	193,000	183,000	175,000	165,000
		16	174,000	236,000	220,000	210,000	200,000	188,000
		17	196,000	266,000	250,000	235,000	224,000	210,000
		18	220,000	300,000	280,000	264,000	250,000	237,000
		19	246,000	330,000	310,000	294,000	280,000	264,000
		20	272,000	370,000	344,000	325,000	310,000	293,000

prepared by Messrs. Babcock and Wilcox, gives the flow of steam through pipes of various sizes and at various pressures. The weight of steam delivered is calculated on a fall of one pound pressure through straight pipes each having a length of 240 times its own diameter.

For any other *loss of pressure* multiply by the square root of the given loss. For any other *length of pipe* divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient, which will give the flow of steam for 1 pound loss of pressure. Conversely, dividing

TABLE XXXIX.

Speed of steam. Sat. 75 ft., superh., 100 ft. per sec.		Steam quantities in lbs. per hour. Working pressure, 200 lbs. = 14 kg. = 13·6 atmospheres.					
		Saturated steam.	Steam superheated by				
			100° F., 55° C.	150° F., 83° C.	200° F., 110° C.	250° F., 140° C.	300° F., 167° C.
ins.							
	½	170	200	190	180	170	160
	¾	390	450	420	400	380	360
	1	690	800	750	700	675	640
	1¼	1,080	1,250	1,170	1,100	1,050	1,000
	1½	1,550	1,800	1,680	1,600	1,520	1,430
	2	2,750	3,200	3,000	2,800	2,700	2,550
	2½	4,300	5,000	4,700	4,400	4,200	4,000
	3	6,200	7,200	6,700	6,400	6,100	5,700
Speed of saturated steam, 90 ft. per sec. Speed of superh. steam, 120 ft. per sec.	3½	10,000	11,700	11,000	10,500	10,000	9,400
	4	13,200	15,300	14,300	13,700	13,000	12,200
	4½	16,700	19,400	18,000	17,400	16,400	15,500
	5	20,600	24,000	22,400	21,400	20,000	19,000
	6	29,600	34,400	32,000	31,000	29,000	27,500
	7	40,000	47,000	44,000	42,000	40,000	37,400
	8	53,000	61,000	57,000	55,000	52,000	49,000
	9	67,000	78,000	72,000	70,000	66,000	62,000
Speed of superh. steam, 140 ft. per sec.	10	82,000	112,000	104,000	99,000	94,000	90,000
	11	100,000	135,000	126,000	120,000	114,000	108,000
	12	119,000	160,000	150,000	142,000	136,000	128,000
	13	140,000	190,000	176,000	167,000	160,000	150,000
	14	160,000	220,000	205,000	194,000	185,000	175,000
	15	185,000	250,000	235,000	222,000	210,000	200,000
	16	210,000	286,000	267,000	253,000	240,000	230,000
	17	240,000	320,000	300,000	286,000	273,000	260,000
	18	267,000	360,000	340,000	320,000	306,000	290,000
	19	300,000	400,000	380,000	360,000	340,000	320,000
	20	330,000	450,000	420,000	395,000	380,000	360,000

the given length by 240 will give the loss of pressure for the flow given in Table No. XL. A differentiation in favour of the turbine must be made when calculating the flow through steam pipes as compared with the intermittent supply to reciprocating engines. This may represent 8 per cent. in favour of the turbine.

TABLE XL.

DIAMETER OF PIPE IN INCHES. LENGTH = 240 DIAMETERS.

Initial gauge pressure lbs. per sq. in.	¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
	Weight of steam per minute in lbs. with 1 lb. loss of pressure.													
100	2·95	5·25	14·5	25·96	39·07	64·18	118·47	195·6	293·1	534·6	862·6	1270·1	2032	2975
120	3·16	5·63	15·5	27·85	41·93	68·87	127·12	209·9	314·5	573·7	925·6	1363·3	2181	3193
150	3·45	6·14	17·0	30·37	45·72	75·09	138·61	228·8	343·0	625·5	1009·2	1486·5	2378	3481
180	3·67	9·28	18·29	33·54	50·70	77·00	147·90	241·8	361·2	674·5	1088·2	1602·9	2564	3754
200	3·83	9·726	18·96	34·40	53·00	80·64	154·00	253·1	377·5	707·0	1139·7	1679·0	2686	3931

Tests for Moisture in Steam.—Tests for moisture in steam can be made by a special form of Barrus wire-drawing calorimeter, the principle of which depends on the fact that dry steam when expanded from a higher to a lower pressure without doing external work becomes superheated, the amount of superheat being dependent on the difference of pressure. If the steam is wet then the moisture must first be evaporated, and thus the superheating will be proportionately less.

The wetness can be deduced with fair accuracy from the following formula:—

$$X = \frac{H - 1146{\cdot}6 - 0{\cdot}48\,(T - 212)}{L} \times 100$$

where H = total heat above 32° in the steam at boiler pressure,

L = latent heat of the same,

T = temperature shown by the lower thermometer in the calorimeter.

When using such an instrument very great care must be taken to calibrate it, about which there are, however, some difficulties.

Reference can be made to works on Thermodynamics for further information.

Fig. 39 shows the arrangement of steam piping adopted by the Author for Bahia Blanca, Argentina.

Here it will be seen that the boilers and engines are back-to-back, thus enabling a simple system to be used. Tracing from boiler to engine, from the boiler-stop valve the 7-inch pipe rises to the highest point in the system and thence falls continually to the lowest point, *i.e.* the engine separator. There is a continuous

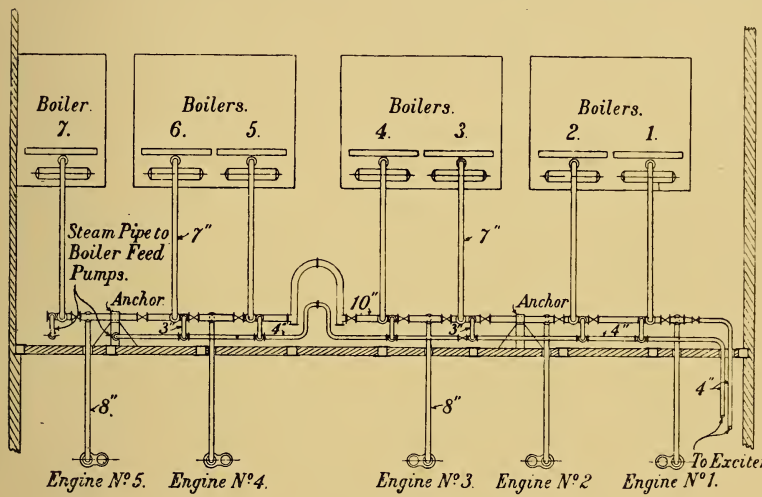


Fig. 39.

header connecting the several branch pipes, 10 inches in diameter and with suitable section valves as shown in the figure. In this case, in addition to the drains from the separators, there are, as shown, pockets riveted up to the header at certain points in order to drain the main header when cut up into sections. To each of these a steam trap is fixed. The section valves are worked both from an upper platform giving access to the boiler tops and also from the ground level. The header is situated in the boiler house, thus giving a better appearance to, and to some extent a lessening of the chances of escaping steam from, a bad joint in the engine-room. The header is anchored at two points only as shown, these and the boiler stop and engine separator flanges are the only fixed

points, and the pipe work is otherwise free to take up its own position, whether steam be on or not. The header is carried on roller supports, and is provided with a large horizontal expansion

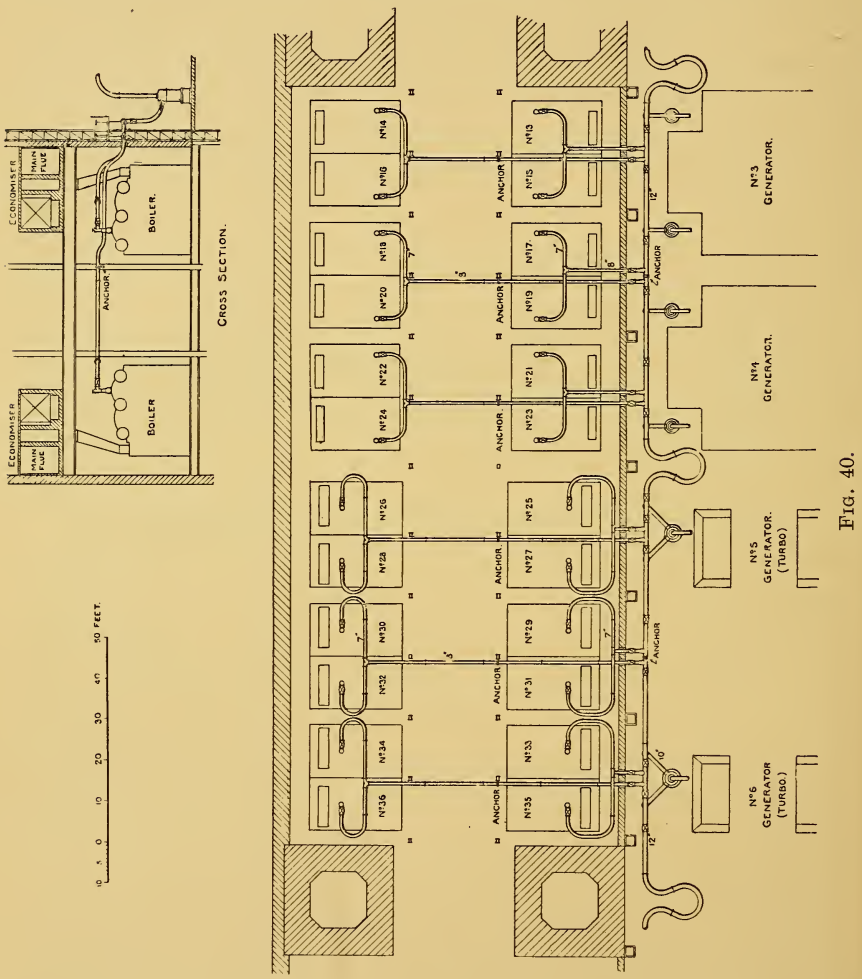


Fig. 40.

bend, midway between the two anchor brackets. As will be seen on reference to the figure, there are several ample bends to give elasticity to and prevent undue stresses upon the system.

Fig. 40 shows the arrangement of pipe work at the Greenwich

Power House of the London County Council. Here the supply is given from a double bank of boilers, each pair of boilers, moreover, being taken as a unit with one common branch pipe (8 inches diameter) to the header. The header is situated in the engine-room in this example, and is anchored midway between each pair of expansion bends as shown in the figure. The long branch pipes from the back row of boilers are each anchored at a stanchion approximately midway. The arrangement of valves will repay study by the designer (particularly in that portion supplying the turbo-generators) since it embodies the safest practice with the greatest simplicity. As in the former example, the branch pipe from the boilers (in this case the back row of boilers) is the highest point and the pipes fall thence to the separators.

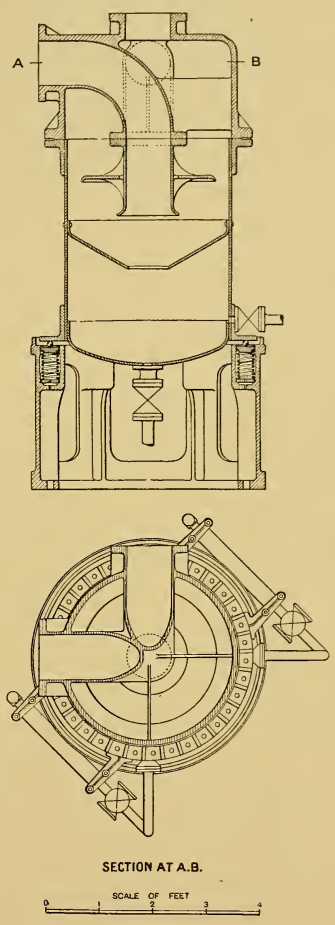


Fig. 41.

An interesting detail of this system is shown in Fig. 41, which illustrates a movable separator adopted by Mr. J. H. Rider in connection with the Greenwich sets. Each separator, which is the lowest part of the main-steam range, is mounted upon special stools with ball bearings and springs, and is thus free to move in any direction, either up, down, or sideways. The water is drained off from the lowest part by duplicate-steam traps and a hand-worked blow-down valve. These separators have proved most effective in practice by relieving the branch pipes from many strains. A separator of this kind may safely be recommended for large-power plants. The Engineering Advisory Board in connection with the London Power Bulk Supply Bills, of which the

Author was a member, were responsible for the designs of a projected very large power house in which an aggregate of 120,000 K.W. of turbo-generators was to have been installed. In this case the "bulkhead" principle was adopted with eight boilers (four pairs) to each 12,000 K.W. turbo-generator. This pipe design is shown in Fig. 42. Here the boilers are necessarily placed at right angles to the turbines on account of the large output of the latter. It will be seen that each pair of boilers had a rated evaporation of 45,000 lbs. per hour, and steam was led away by

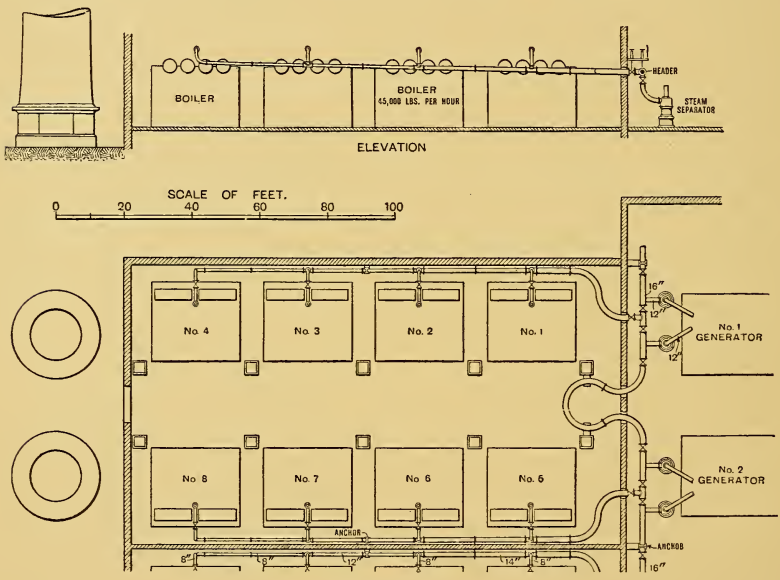


FIG. 42.

an 8-inch supply pipe leading up successively through a 12-inch, 14-inch, and ultimately a 16-inch pipe (as the supply from each successive boiler was picked up) to a 16-inch connecting header. Each turbine was to have been supplied from two 12-inch branch pipes as shown in the figure. Here, again, the same principles as to drainage, as also illustrated in Fig. 41, were adopted.

The above descriptions of steam-pipe systems embody the principles laid down at the beginning of this chapter. On no account should ring mains be used in steam-pipe work—they are things of the past, involving unnecessary expense, complications,

and increased losses through radiation, increased danger from water collection and water hammer, and without giving any additional security to the supply for which reason they were originally adopted.

Drainage of Steam Pipes.—As faulty drainage arrangements and improper provision for contraction and expansion have been the two primary causes of trouble in steam-pipe systems, it may be well to supplement the remarks made before by further example. In any pipe system, however well designed, owing to the necessary cutting up into sections at times, there is a tendency to accumulate water in the "dead" sections through slight leaks past the section valves. Provision must therefore be made to get rid of this water without danger. All draining arrangements should therefore satisfy the three following conditions:—

(*a*) They must keep the pipe system entirely free from water when no steam is passing to the engines; *i.e.* it should be possible to open the engine stop-valve or bye-pass at any time without risk of carrying over water.

(*b*) Should any water form in the pipes while carrying steam to the engines, or should any water come over from the boilers through priming, it must be prevented (1) from causing water hammer in the system, or (2) from reaching the engines.

(*c*) Should any individual sections be laid off while neighbouring sections are alive, provision must be made to remove any possible accumulation of water in the dead section due to leakage, before the dead section is again opened out to the live steam.

To meet conditions A and B the pipes must be arranged so as to allow any water to flow by gravity (and with the steam) to certain defined points where it can be collected and drained off.

To meet condition C it is sometimes necessary to have supplementary drain pipes on the main header or boiler side of the boiler branch pipe. If possible always avoid these, but when, owing to the relative positions of boilers and engines, they are absolutely necessary, then let them be readily accessible. It must be recollected that these auxiliary drains are only for use when sections of the pipes have to be laid off between the two points of natural drainage formed by the engine separators. All high-pressure drains, through steam traps or direct blow-down, should discharge

back to the hot well so as to prevent loss of heat and good water.

Expansion of Steam Pipes.—The second point is to make due allowance for expansion and contraction. The coefficient of expansion of a steel pipe is 0·0000067 per degree Fahr., which represents an expansion of about 2·5 inches per 100-feet length of pipe in raising the temperature of the pipe from normal air temperature to 380°, the corresponding temperature of saturated steam at 180 lbs. pressure. A further allowance of 0·8 inch per 100 feet must be made for every 100° of superheat. Thus the allowance made must be $3\frac{1}{3}$ inches per 100 feet with superheated

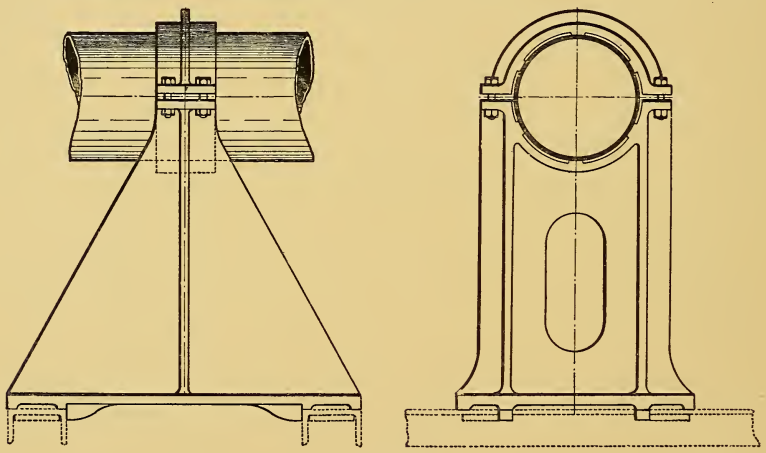


Fig. 43.

steam of a total temperature of 480° Fahr. The strains thus set up are of course taken care of (*a*) by suitable bends giving elasticity to the system; (*b*) by reducing the summation effect on a long length by anchoring the pipe at suitable intervals and thus reducing the expansion on each section: this smaller value being taken up by the various bends.

The movements thus set up by expansion or contraction are minimized and also controlled. Anchoring is usually effected by brackets bolted up to the boiler-house stanchions as shown in Fig. 43. A slab of asbestos should be inserted between the stool and the steel bracket so as to prevent conduction of heat. The remainder of the pipe is then carried on suitable rollers and

brackets, and is thus free to move. The rollers should be mounted on set screws for the purpose of accurate levelling.

Standardization of Valves.—In laying out a system reduce the number of valve sizes to a minimum so as to standardize as far as possible and to reduce spare parts. All steam valves must be arranged with outside threaded spindles, and the full-way valve must always be used on horizontal lengths so as to give a clear and unobstructed bore through the system. Valves above 6 inches in diameter must always have bye-passes fitted. For vertical pipes the Ferranti type of valve is strongly to be recommended, the valve face and seating being so much smaller to maintain than in the case of the ordinary full-bore valve. Cast steel bodies and renewable valve seats are used in the best practice. Each valve should be tested at the makers' works, both under hydraulic pressure to at least twice the working pressure and by steam at a pressure of 200 lbs.

Lagging.—Special attention must be paid to the thorough insulation of steam piping, flanges, and valve bodies, and to the materials used. Every square foot of bare pipe passing superheated steam at a temperature of 337° Fahr. (100 lbs. by gauge) will represent a loss of 625 B.Th.U. with a surrounding atmospheric temperature of 62° Fahr. There are various materials in general use, and tests show that the percentage saving on bare pipes are as follows:—

Hair felt	87 per cent.
Magnesia	87 „ „
Asbestos	89 „ „
Silicate cotton	90 „ „

There are various methods for applying lagging. There is the magnesia sectional covering which makes a very neat and thermally effective lagging, but has the objection that it will not stand much handling. It is, however, for its cost perhaps as effective a covering as can be obtained.

Hair felt is now never used with the higher temperatures owing to the danger of combustion. There is much to be gained by adopting a removable covering especially for flange covers and valves.

The Author inclines to the use of removable asbestos coverings

finished with planished sheet steel; this is more expensive than the magnesia sectional covers, but is more durable. Either of these types, however, provides a good lagging.

The lagging should be specified not to char, perish, or disintegrate when exposed continuously to a temperature of 420° C.; and the thickness should be such that the pipes when carrying superheated steam of a specified temperature should not lose more than 0·8 B.Th.U. per square foot of pipe surface (measured before the lagging is applied) per degree difference (Centigrade) between the steam and the surrounding atmosphere.

The following Table, No. XLI., gives the properties of saturated steam:—

TABLE XLI.

PROPERTIES OF SATURATED STEAM.

Absolute pressure in lbs. per sq. in.	Temperature or boiling-point in degrees Fahr.	Total heat in thermal units per lb. steam from 0° Fahr.	Latent heat in thermal units per lb.	Volume (cubic feet per lb.).	Weight of 1 cubic foot of steam in lbs.	Cubic feet of steam from 1 cubic foot of water at 62° Fahr.
1.	2.	3.	4.	5.	6.	7.
1	102·0	1145·0	1042·9	330·36	0·0039	20,600
2	126·4	1152·2	1025·8	172·08	0·0058	10,730
4	153·1	1160·1	1006·8	89·62	0·0112	5,589
5	162·3	1163·0	1000·3	72·66	0·0138	4,580
8	183·0	1169·2	985·7	46·69	0·0214	2,911
10	193·3	1172·3	978·4	37·84	0·0264	2,360
12	202·0	1175·0	972·2	31·88	0·0314	1,988
15	213·1	1178·4	964·3	25·85	0·0387	1,611
18	222·5	1181·2	957·7	21·78	0·0459	1,357
20	228·0	1182·9	952·8	19·72	0·0507	1,229
22	233·3	1184·5	949·9	18·03	0·0555	1,123
25	240·5	1186·6	945·3	15·99	0·0625	996
30	250·5	1189·8	937·9	13·46	0·0743	838
35	259·4	1192·5	931·6	11·65	0·0858	726
40	267·0	1194·9	926·0	10·27	0·0974	640
45	274·5	1197·1	920·9	9·18	0·1089	572
50	281·0	1199·1	916·3	8·31	0·1202	518
55	287·1	1201·0	912·0	7·61	0·1314	474
60	292·6	1202·7	908·0	7·01	0·1425	437
65	298·0	1204·3	904·2	6·49	0·1538	405
70	302·8	1205·8	900·8	6·07	0·1648	378
75	307·5	1207·2	897·5	5·68	0·1759	353
80	312·1	1208·5	894·3	5·35	0·1869	333
85	316·1	1209·9	891·4	5·05	0·1980	314
90	320·3	1211·1	888·5	4·79	0·2089	298
95	324·0	1212·3	885·8	4·55	0·2198	283
100	327·7	1213·4	883·1	4·33	0·2307	270
105	331·2	1214·4	880·7	4·14	0·2414	257
110	334·6	1215·5	878·3	3·97	0·2521	247
115	337·9	1216·5	875·9	3·80	0·2628	237

Absolute pressure in lbs. per sq. in.	Temperature or boiling-point in degrees Fahr.	Total heat in thermal units per lb. steam from 0° Fahr.	Latent heat in thermal units per lb.	Volume (cubic feet per lb.).	Weight of 1 cubic foot of steam in lbs.	Cubic feet of steam from 1 cubic feet of water at 62° Fahr.
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**
120	341·1	1217·4	873·7	3·65	0·2738	227
125	344·2	1218·4	871·5	3·51	0·2845	219
130	347·2	1219·3	869·4	3·38	0·2955	211
135	350·1	1220·2	867·4	3·27	0·3060	203
140	352·9	1221·0	865·4	3·16	0·3162	197
145	355·6	1221·9	863·5	3·06	0·3273	190
150	358·3	1222·7	861·5	2·96	0·3377	184
155	361·0	1223·5	859·7	2·87	0·3484	179
160	363·4	1224·2	857·9	2·79	0·3590	174
165	366·0	1224·9	856·2	2·71	0·3695	169
170	368·3	1225·7	854·5	2·63	0·3798	164
175	370·8	1226·4	852·9	2·56	0·3899	155
180	373·0	1227·1	851·3	2·49	0·4009	151
185	375·3	1227·8	849·6	2·43	0·4117	148
190	377·5	1228·5	848·0	2·37	0·4222	144
195	379·6	1229·2	846·5	2·31	0·4327	141
200	381·8	1229·8	845·0	2·26	0·4431	135

Feed and Air-pump Discharge Pipes.—Feed piping at one time was invariably of copper. This is quite unnecessary, especially having regard to the modern treatment of feed water. Feed pipes are now invariably made from weldless mild steel with wrought steel flanges screwed on and expanded. Tee pieces are usually of high-grade cast iron.

Table No. XLII. sets out the usual pipes used in feed-water systems.

TABLE XLII.

STANDARD SIZES OF FEED PIPES.

Bore of pipe.	Thickness of pipe.	Diameter of flange.	Thickness of flange.	Radius of bends.	Tees : centre to flange face.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.		
2	$\frac{3}{16}$	6	$\frac{11}{16}$	6	5	$4\frac{1}{2}$	4	$\frac{5}{8}$
$2\frac{1}{2}$	$\frac{3}{16}$	$6\frac{1}{2}$	$\frac{11}{16}$	$7\frac{1}{2}$	$5\frac{1}{2}$	5	4	$\frac{5}{8}$
3	$\frac{1}{4}$	$7\frac{1}{4}$	$\frac{3}{4}$	9	6	$5\frac{3}{4}$	4	$\frac{5}{8}$
$3\frac{1}{2}$	$\frac{1}{4}$	8	$\frac{3}{4}$	$10\frac{1}{2}$	$6\frac{1}{2}$	$6\frac{1}{2}$	4	$\frac{5}{8}$
4	$\frac{1}{4}$	$8\frac{1}{2}$	$\frac{7}{8}$	12	7	7	4	$\frac{5}{8}$

Circulating Water Pipes.—The following table gives the sizes of circulating water pipes. These are generally cast vertically from close-grained iron, and are specified to be of uniform thickness

and smooth inside and out, and coated inside and out with Angus Smith's composition. In most cases such pipes are flanged, but there are places where an ordinary spigot and socket joint will do for low-level pipes not subject to any great head. In many cases riveted galvanized iron pipes should be used, especially if freight charges and difficulties of transportation have to be considered. Suction pipes are fitted with rose suction-boxes. Appendix II. should be consulted for velocities of water in pipes.

TABLE XLIII.

GALVANIZED IRON CIRCULATING WATER PIPING.

Bore of pipe.	Thickness of pipe.	Diameter of flange.	Thickness of flange.	Radius of bends.	Tees : centre to face of flange.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.		
14	$\frac{5}{16}$	$20\frac{3}{4}$	$\frac{5}{8}$	63	17	$18\frac{1}{2}$	16	$\frac{7}{8}$
15	$\frac{5}{16}$	$21\frac{3}{4}$	$\frac{5}{8}$	$67\frac{1}{2}$	18	$19\frac{1}{2}$	16	$\frac{7}{8}$
16	$\frac{5}{16}$	$22\frac{3}{4}$	$\frac{5}{8}$	80	19	$20\frac{1}{2}$	16	$\frac{7}{8}$
18	$\frac{5}{16}$	$25\frac{1}{4}$	$\frac{5}{8}$	90	21	23	20	$\frac{7}{8}$
20	$\frac{5}{16}$	$27\frac{3}{4}$	$\frac{5}{8}$	110	23	$25\frac{1}{4}$	20	$\frac{7}{8}$
21	$\frac{5}{16}$	29	$\frac{3}{4}$	$115\frac{1}{2}$	24	$26\frac{1}{2}$	24	$\frac{7}{8}$
24	$\frac{5}{16}$	$32\frac{1}{2}$	$\frac{3}{4}$	132	27	$29\frac{3}{4}$	24	1
27	1	40	$\frac{3}{4}$	$148\frac{1}{2}$	30	$36\frac{3}{4}$	24	1
30	1	43	$\frac{3}{4}$	165	33	$39\frac{3}{4}$	24	1

Rotary Strainers.—Where circulating water is drawn from a river or other source containing straw, grit, and other substances tending to choke the condenser tubes, etc., a rotary strainer of the type designed by Messrs. Bailey and Jackson of the City of London Electric Supply Co. can be adopted with a guarantee that such injurious "flotsam" will be strained off and prevented from entering the circulating system. Fig. 44 shows one of these strainers. This consists of a casing in which is a wheel revolving very slowly and containing between its spokes, sheet brass-strip grids so interlaced as to form small channels for the passage of the circulating water. On both sides of the wheel, the casing forms a chamber, each chamber being divided into two compartments by a partition. The first chamber receives the unstrained water; which is strained by being forced through the revolving grid. The return water, after passing through the condenser system, enters the other chamber and washes out the material caught up by the strainer

and carries it away with the discharge water. Fig. 45 shows the lay-out of the circulating water-system (designed for the Greenwich Power House) and the rotary strainers inserted will be seen, together with the penstocks and rough straining racks. The centrifugal pumps and cross-over pipes for alternate use as suction and discharge are also shown.

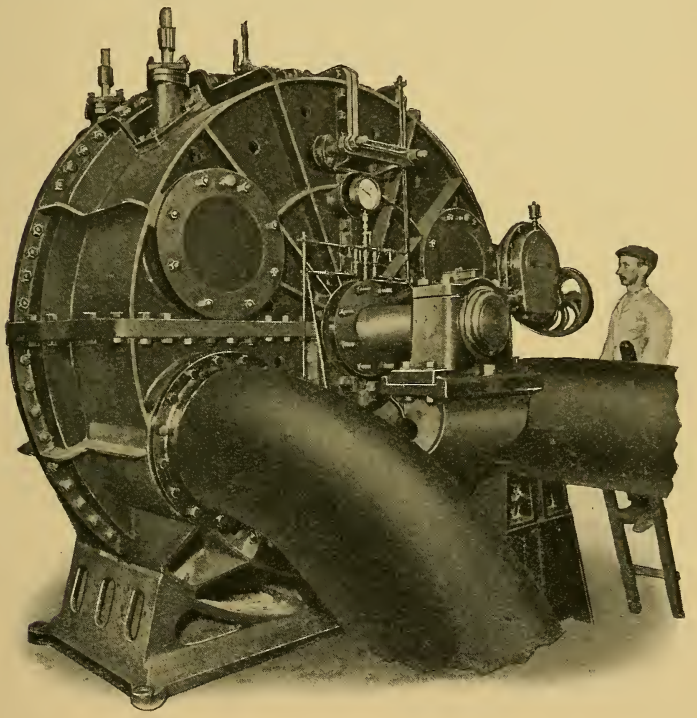


Fig. 44.

Exhaust Heads.—Atmospheric vent pipes should terminate in an exhaust head which serves two purposes, viz. to give the escaping steam a rotary motion and thus to throw off some of the moisture contained in it against suitable baffles and thus prevent a nuisance to surrounding property; and, secondly, by decreasing the velocity, to prevent any chance of atmospheric vibration.

Pipe Supports.—Wherever possible all horizontal lengths of pipe should be carried on rollers and supported from below. The

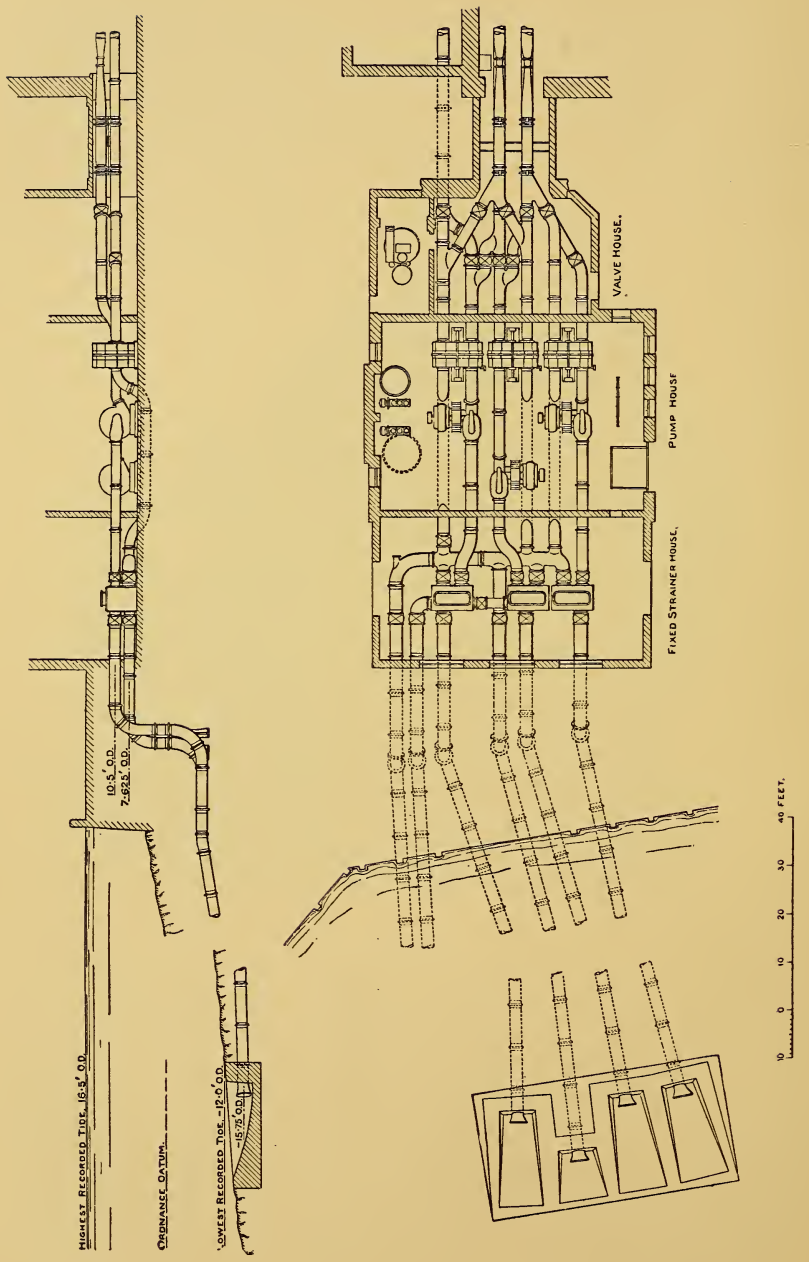

VALVE HOUSE.
PUMP HOUSE
FIXED STRAINER HOUSE.
HIGHEST RECORDED TIDE +16·5' O.D.
ORDNANCE DATUM
LOWEST RECORDED TIDE -12·0' O.D.
10·5' O.D.
7·625' O.D.
-15·75' O.D.
10 0 10 20 30 40 FEET.

FIG. 45.

rollers are carried on steel wall-brackets, or occasionally on columns.

Cast-iron boxes with roller supports should be provided where pipes go through walls.

Heat insulation-pads should be inserted between the roller and the supporting bracket where the latter is bolted up to the steel structural framework of the building.

Anchor brackets are made up from steel channels and lattices, or cast, as shown in detail in Fig. 46. It is better to avoid

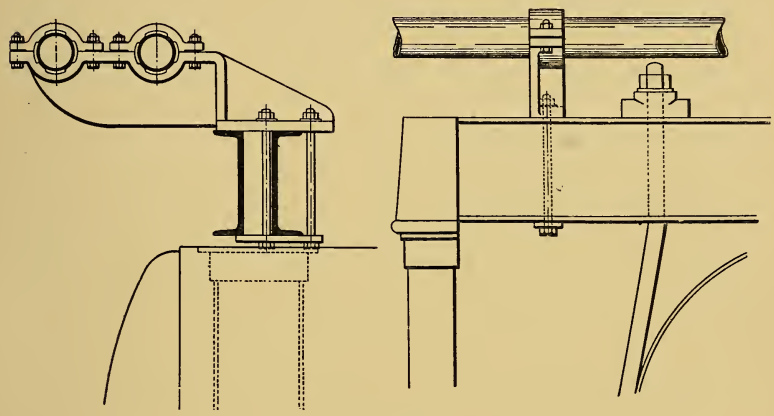


Fig. 46.

suspending pipes from swinging rods or straps, as these are less alignable than rollers and more likely to set up stresses on pipe flanges owing to the extension of the rods, or to settlement, or giving of the ties or other and less rigid parts from which they may be slung. Even if slung from brackets bolted up to the building structure, not so good a job is made as when the pipes are supported on brackets and rollers. This is, of course, especially applicable to the larger sizes.

Exhaust Piping.—Exhaust pipes for small sets are usually made of cast iron; and for larger sets up to and including 8-inch pipes of lapwelded mild steel with steel flanges screwed and expanded on. For pipes above 8-inch diameter exhaust pipes should be made of riveted galvanized sheet mild steel, with stout angle-iron flanges riveted to the pipe.

The following table gives the normal dimensions of the usual sizes of exhaust pipes:—

TABLE XLIV.

STANDARD EXHAUST PIPING.

Bore of pipe.	Thickness of pipe.	Diameter of flange.	Thickness of flange.	Radius of bends.	Tees: centre to face of flange.	Diameter of bolt circle.	No. of bolts.	Diameter of bolts.
ins.	ins.	ins.	ins.	ins.	ins.	ins.		
2	5/16	6½	1	6	3¼	5	4	⅝
3	¼	8	1¼	9	4	6½	8	⅝
4	¼	9	1⅜	12	4¾	7½	8	⅝
5	¼	11	1½	15	5½	9¼	8	¾
6	¼	12	1½	18	6½	10¼	12	¾
7	¼	13¼	1⅝	24½	7¼	11½	12	¾
8	¼	14½	1⅝	28	8¼	12¾	12	¾
9	5/16	16	1¾	31½	9	14	12	⅞
10	5/16	17	1⅞	40	10	15	12	⅞
12	5/16	19¼	2	48	11¾	17¼	16	⅞
14	5/16	21¾	2⅛	63	13½	19½	16	1
15	⅜	22¾	2⅛	67½	14¼	20½	16	1
16	⅜	24	2¼	80	15¼	21¾	20	1
18	⅜	26½	2⅜	90	17	24	20	1⅛
20	⅜	29	2½	110	18¾	26½	24	1⅛
21	⅜	30	2⅝	115½	19½	27½	24	1⅛
24	⅜	33½	2¾	132	22¼	30¾	24	1¼

Exhaust Separators.—Table No. XLV. gives the standard dimensions of exhaust separators which are used in the exhaust pipes of reciprocating engines between the engine and its condenser. A small pump is used to withdraw the oil and water collected in the separator, and the discharge should be taken to a small skimming tank so as to recover the oil.

TABLE XLV.

STANDARD LIST OF OIL SEPARATORS.

Approximate indicated horse power.	Lbs. of steam per hour.	Approximate diameter of exhaust pipe.	Diameter of shell of separator.	Height of shell of separator.	Face to face of flanges	Approximate weight.
		ins.	ft. ins.	ft. ins.	ft. ins.	tons.
125	2,500	6	3 0	3 6	4 2	0·6
150	3,000	6	3 0	4 0	4 2	0·75
175	3,500	6	3 3	4 0	4 6	0·775
200	4,000	7	3 3	4 3	4 6	0·8
250	5,000	7	3 3	4 6	4 6	0·9
300	6,000	8	3 6	5 6	4 9	1·25
400	6,750	9	3 9	5 9	5 0	1·35

Approximate indicated horse power.	Lbs. of steam per hour.	Approximate diameter of exhaust pipe.	Diameter of shell of separator.	Height of shell of separator.	Face to face of flanges.	Approximate weight.
		ins.	ft. ins.	ft. ins.	ft. ins.	tons.
500	7,500	10	4 0	6 0	5 6	1·75
550	8,250	10	4 0	6 6	5 6	1·8
600	9,000	11	4 3	6 3	5 9	1·9
700	10,500	12	4 3	7 0	5 9	2·15
800	12,000	14	4 6	7 0	6 0	2·35
850	12,750	15	4 6	7 6	6 0	2·4
900	13,500	16	4 6	8 0	6 0	2·5
1,000	15,000	18	4 9	8 0	6 3	2·7
1,100	16,500	18	5 0	8 0	6 6	2·8
1,200	18,000	19	5 3	8 0	6 9	2·95
1,300	19,500	20	5 6	8 0	7 0	3·1
1,400	21,000	21	5 9	8 0	7 3	3·4
1,500	22,500	22	6 0	8 0	7 6	3·5
1,750	26,250	22	6 6	8 0	8 0	4·0
2,000	30,000	24	6 6	9 0	8 0	4·1
2,250	33,750	24	6 9	9 0	8 3	4·25
2,500	37,000	26	7 3	9 0	8 9	4·75
2,750	41,250	28	7 6	9 0	9 0	5·0
3,000	45,000	30	7 6	10 0	9 0	5·45
3,500	52,500	32	8 0	10 0	9 6	5·95
4,000	60,000	34	8 3	11 0	9 9	6·55
5,000	75,000	36	9 0	11 6	10 6	8·1
6,400	96,000	38	9 9	12 6	11 3	11·75
10,000	150,000	40	11 0	15 0	12 6	13·25

CHAPTER VI

STEAM GENERATORS

The selection of the prime mover for any power house depends on the size of the plant and nature of the service. Bearing in mind the principle laid down in a preliminary chapter, that eight units represent the best number to instal in a completed power house of large size, it is comparatively easy to determine the size of each individual unit. This must not be taken as a hard-and-fast rule, but it may be worked to as an approximate one. It enables one set to be dismantled, another to be standing by, and six to be working at rated load, or five at load and a quarter. There is thus 75 per cent. of the installed plant which can be safely ranked as revenue producing. The factors to be considered when fixing the type of plant are—size; type of generator, whether direct current or alternating; geographical position of power house, accessibility for material and also for skilled repairs, and nature of service, *i.e.* whether general power and lighting supply, tramway, or railway supply, and so forth.

Reciprocating engines are divided empirically into high-speed, medium-speed, and low-speed classes. The high-speed are those with speeds varying from 250 to 625 R.P.M. and with piston speeds of about 750 feet per minute. The slow-speed sets usually run from 83 to 107 R.P.M. with a piston speed of 750 feet per minute. For alternating current generators above 750 K.W. output turbines are increasingly used, especially in the larger sizes of 2000 K.W. and upward, now so largely adopted. The following Table, No. XLVI., sets forth the relative speed, weights, approximate costs, and steam consumptions of these various types of plant. The prices must, of course, be only taken as relative since the conditions

of any particular contract and many other things arise to vary the price. The relative figures, however, will serve for comparison.

TABLE XLVI.

Type.	Rated output.	Speed.	Total weight of engine.	Weight per B.H.P.	Weight of Fly-wheel.	Steam consumption. Full load. 26 ins. vac.	Approximate total cost of engine.	Approximate total cost of engine and generator.	Cost per B.H.P. engine.	Cost per K.W. steam generator.	Floor space per K.W.
	B.H.P.	R.P.M.	tons.	tons.	tons.	lbs.	£	£	£	£	sq. ft.
Slow-speed	5,300	94	280	0·053	40	16·88	22,600	29,250	4·26	8·00	0·46
Medium-speed	2,000	188	110·00	0·055	17	17·01	6,046	11,296	3·02	7·53	0·21
do.	1,500	188	69·00	0·046	13	17·62	5,162	9,587	5·16	8·56	0·25
do.	1,100	188	54·00	0·050	12	17·75	2,900	6,500	4·60	8·25	0·30
High-speed	1,450	250	68·35	0·047	11·0	17·60	3,903	8,180	2·69	7·58	0·24
do.	1,100	250	49·25	0·044	10	17·75	2,647	5,892	2·40	7·18	0·28
do.	570	375	14·50	0·025	5	19·40	1,284	3,965	2·25	9·32	0·30

Broadly speaking, there can be no doubt that for electrical power houses the tendency of modern practice is to use reciprocating engines when the size of unit does not exceed 750 K.W. output, especially with direct-current generators, having regard to economical speeds; and to use turbines always for larger units.

The universal recognition, nowadays, of the necessity of reducing capital expenditure on power houses to a minimum in order to obtain the soundest commercial results and to avoid waste, really reduces the modern plants available to high-speed reciprocating sets for smaller sizes, and turbines for the larger sizes. The Author does not therefore propose to enter into a lengthy description of the slow-speed horizontal, vertical, or "grasshopper" types of engine, since (*a*) their greater cost, (*b*) greater weight affecting foundations, (*c*) greater floor space affecting the size and cost of buildings, and (*d*) the greater cost of attendance, really puts this type out of court except in very special circumstances. No doubt excellent work has been done by such engines, and low steam consumption and low cost of repairs can certainly be claimed for any of those made by first-class engine builders, but except in the case of direct-current generators of larger sizes—which are becoming increasingly rarer—the large

size slow-speed engine will probably never be used in future power houses, or in extensions of existing ones. A good example of a modern horizontal cross compound drop-valve engine is shown in Plate VII. This represents a 3000-I.H.P. Musgrave engine coupled to a B.T.H. 2000-K.W. generator running at 83 R.P.M. The cylinders are 31 inches and 74 inches in diameter respectively, by 52-inch stroke. The fly-wheel weighs 120 tons, 75 tons of which are in the rim. The set is capable of developing 50 per cent. overload and 100 per cent. momentarily with steam at 150 lbs., and when exhausting into a 26-inch vacuum. The engine requires a floor space of 1 square foot per K.W. normal rating, this area also covering the condenser pumps. The condenser itself in this case, being of the barometric type, is placed outside of the engine-room.

The high-speed engine will, however, probably long be retained for small units of plant. The Author suggests that from 750 to 1000 K.W. is the limit beyond which all present considerations of cost and general economy point to the adoption of steam turbines.

The following Table, No. XLVII., gives the standard sizes and speeds adopted by the Engineering Standards Committee with the concurrence of British engine builders:—

TABLE XLVII.

Rated output in K.W.	Approximate B.H.P.	Revolutions per minute at rated output.		
		Slow.	Medium.	High.
100	160	107	250	500
150	220	107	250	428
200	290	107	250	375
250	360	107	250	375
300	430	94	214	375
400	570	94	214	375
500	720	94	214	300
750	1,100	83	188	250
1,000	1,450	83	188	250
1,500	2,140	83	188	—
1,750	2,500	83	188	—

In these the full load of the steam engine expressed in K.W. is assumed to be 110 per cent. of the rated load of the generator.

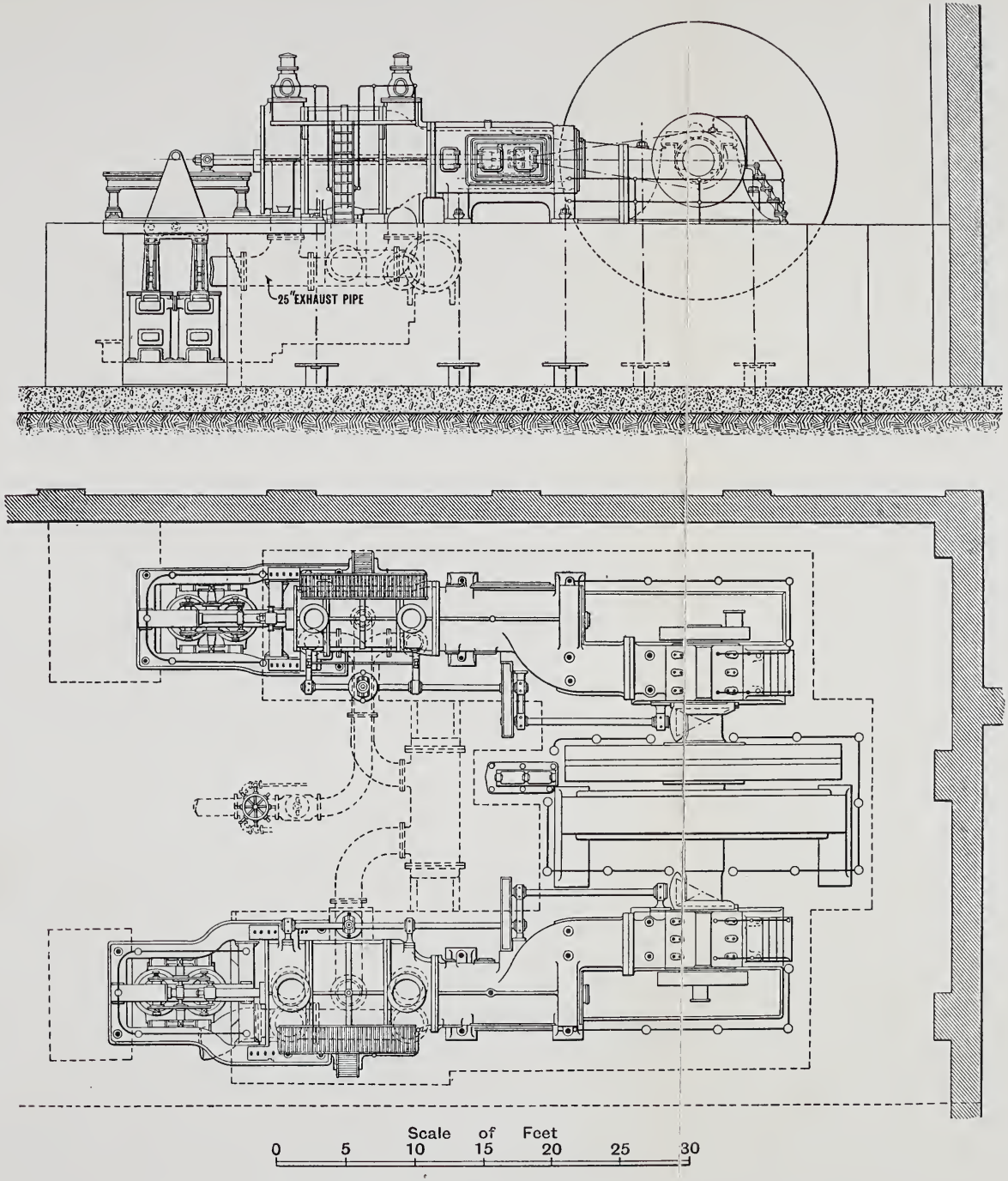


PLATE VII.—3000 I.H.P. MUSGRAVE ENGINE AND GENERATOR.

[*To face page* 146.

The rated load of the generator is the output at which it will work continuously for six hours, within the limits of certain defined temperature rises, viz. stationary and moving coils, when measured by resistance, 60° C., and moving coils measured by thermometer, 50° C., assuming the air temperature in the test-room not to exceed 25° C.

The advantages of high-speed sets are, reduction in the size of generator, compactness, small floor space required and small weight per H.P. (see Table No. XLVI.). They are always arranged with a self-oiling system, and are throttle governed with an auxiliary automatic cut-off. Engines up to 500 K.W. are usually of the compound type, and above 500 K.W. are arranged for triple expansion. This, of course, also depends on the steam pressure available at the stop valve. Willans, in his classic paper read before the Inst. of Civil Engineers, vol. xciii., showed that triple-expansion engines became more economical when the stop valve pressure exceeded 160 lbs. Steam jacketing is found to be unnecessary, owing to the high revolutions per minute. A large fly-wheel is invariably fixed, and the recommendation is that this, plus the weight of the generator rotor, shall be such that the cyclic irregularity shall not exceed the following rule, viz. the maximum permissible variation in speed of the generator throughout one revolution shall not exceed $\frac{1}{30}$th of the angle between two poles. That is to say, the permissible variation in the amount the rotating part forges ahead plus the amount it lags behind the position of uniform rotation shall not exceed 6° in a two-pole machine, 3° in a four-pole machine, and 1·2° in a ten-pole machine. Increased fly-wheel effect has to be given to engines designed for colliery, winding, and traction work.

Fig. 47 shows a typical engine built to the Author's general specification. This engine is rated at 1500 B.H.P. continuously at a speed of 188 R.P.M., with an initial pressure of 180 lbs. per square inch, superheated 56° C. (absolute temperature of steam 247° C.) and exhausting into a 26-inch vacuum. The principal features of this set (which may be taken as typical of all well-built, high-speed sets) are triple expansion, the dimensions of the cylinders being $21\frac{1}{2}'' \times 34'' \times 54'' \times 24''$ stroke. Ratio of connecting rod to stroke 1 : 2·75. Floor space per B.H.P. 0·2 square feet.

Throttle governed, with automatic cut-off gear driven through a steam relay and acting on a rifled liner. Motor-speeding gear for paralleling purposes; duplicate oil-pumps and strainers; water-cooling pipes for crank chamber; tail rods to each cylinder; heavy fly-wheel proportioned to the revolving masses and inertia diagram of the ngine, low steam consumption and interchange-ability of parts with sister engines. The steam consumptions guaranteed, in pounds of water per kilowatt-hour, measured at

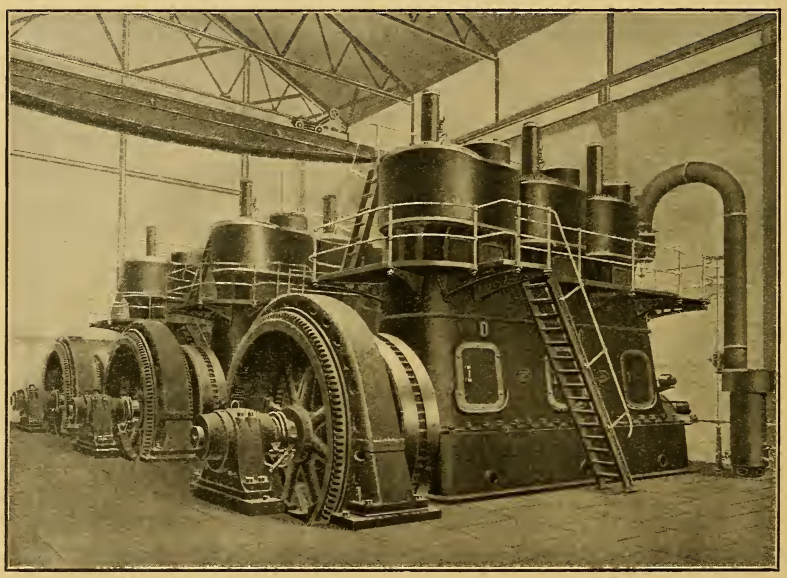


Fig. 47.

the alternator terminals, and at unity power factor, when working under the specified conditions of steam pressure (180 lbs.) superheat (100° Fahr.) and vacuum (26 inches), were as follows :—

One and a quarter load.	Full load.	Three-quarter load.	Half load.	Quarter load.
lbs. 17·68	lbs. 17·58	lbs. 18·14	lbs. 19·15	lbs. 22·99

The pistons of the high-pressure and intermediate-pressure

cylinders are of cast iron, but the low-pressure piston is made of wrought steel. The piston and valve rods, which are $5\frac{3}{4}$ inches and 3 inches in diameter respectively, are made of crucible cast steel, and are all fitted with United States metallic packing. There is no soft packing-gland in the engine. The cylinders are mounted on distance-piece castings, in which the exhaust branches are formed. A metallic scraper gland is fitted to all rods, at the top of the frame, to prevent oil from the crank chamber being drawn upwards, and at the same time to prevent leakage from the cylinder glands getting into the crank chamber.

The crank shaft is made from a solid forging of acid mild steel with a tensile strength of 28·32 tons, and an elongation of 25 per cent. in a test length of 8 inches. Balance-weights are fitted to all cranks. The fly-wheel, which weighs 13 tons, is bolted to a large coupling forged solid with the shaft, the same bolts being used for attachment to the alternator coupling.

Governing is effected by the control of the throttle-valve in the usual way, and also by means of an automatic expansion gear which is fitted to the high-pressure cylinder. The centrifugal governor is fixed on the end of the crank shaft and is directly connected to the throttle-valve through a bell-crank lever. In addition, the governor is connected to the automatic expansion gear through a second arm of the bell-crank lever, as shown in Fig. 48. The expansion gear varies the cut-off in the high-pressure cylinder from 40 to 85 per cent. of the stroke, according to the load on the engine. The alteration in cut-off is effected by slightly rotating the high-pressure valve, which has angular ports, and works across corresponding angular ports in the liner. By means of this rotation, the lead of the valve and the cut-off are varied. The engine speed can be varied 5 per cent. up or down while the engine is running, and a speeder gear is fitted which is operated by an electric motor fixed above the governor casing. The motor can be started, stopped, and reversed by means of a two-way switch on the switchboard, and a knock-out gear is fitted to prevent over-winding in either direction.

Forced lubrication is supplied to all working parts, including the governor, by two valveless oil pumps worked from the low-pressure valve eccentric. These pumps are fitted in a trough

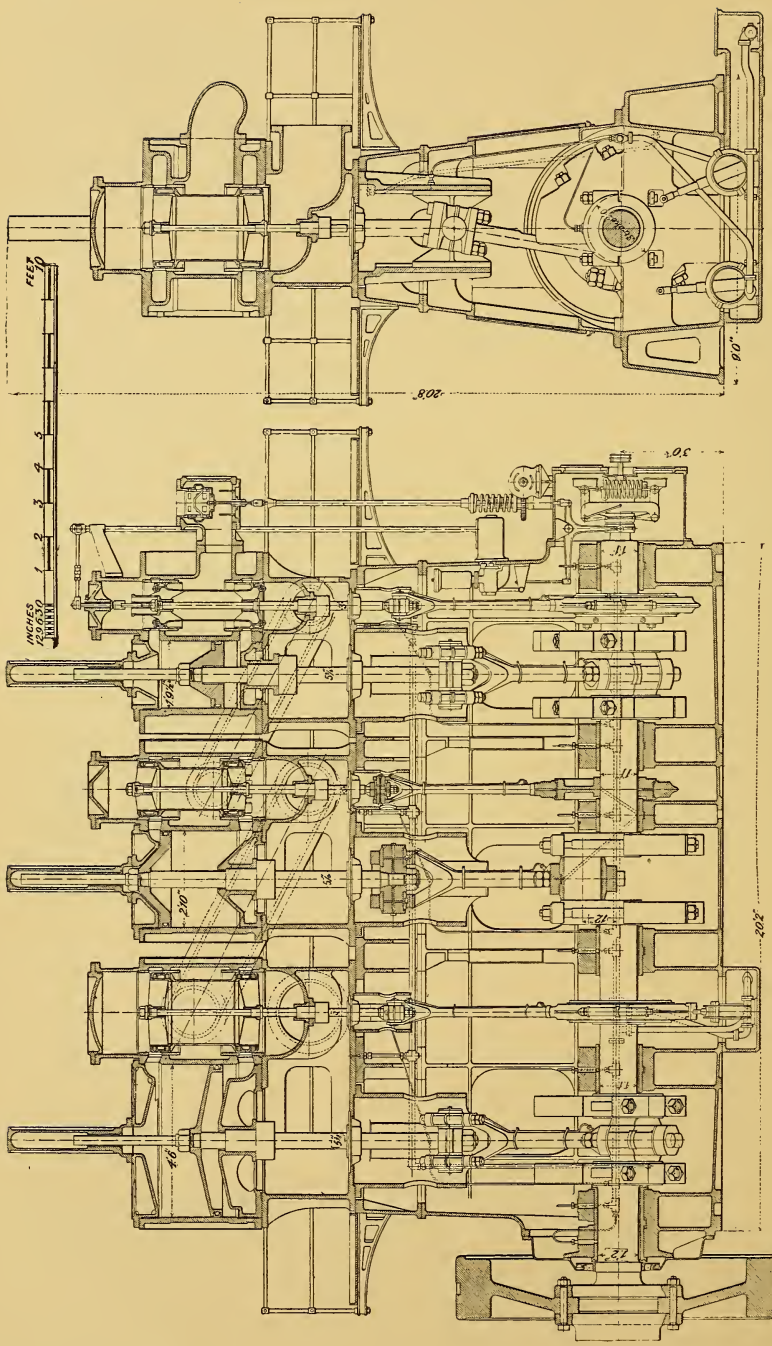


FIG. 48.

below the bed-plate which extends some distance beyond the back of the engine, and is fitted with hinged doors arranged to lift upwards and giving access to the oil-strainers, through which all the oil is drawn before being delivered to the working parts.

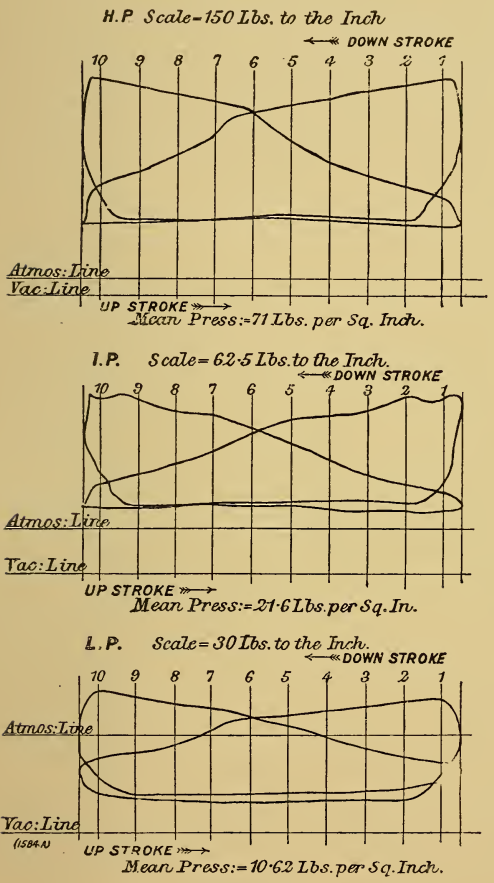

H.P Scale-150 Lbs. to the Inch
DOWN STROKE
10 9 8 7 6 5 4 3 2 1
Atmos: Line
Vac: Line
UP STROKE
Mean Press:-71 Lbs. per Sq. Inch.
I.P. Scale = 62·5 Lbs. to the Inch.
DOWN STROKE
10 9 8 7 6 5 4 3 2 1
Atmos: Line
Vac: Line
UP STROKE
Mean Press:-21·6 Lbs. per Sq. Inch.
L.P. Scale = 30 Lbs. to the Inch.
DOWN STROKE
10 9 8 7 6 5 4 3 2 1
Atmos: Line
Vac: Line
(1584-N)
UP STROKE
Mean Press:-10·62 Lbs. per Sq. Inch.

Fig. 49.

HIGH PRESSURE.
UP STROKE
1 2 3 4 5 6 7 8 9 10
Effective Steam Press. on Piston.
Inertia and Dead Wt. Line
Force acting on Crosshead.
13 14 15 16 17 18 19 20 21 22 23 24
Scale 1 Inch -180 Lbs.
10 9 8 7 6 5 4 3 2 1
Effective Steam Press. on Piston.
Inertia and Dead Wt. Line
Force acting on Crosshead
12 11 10 9 8 7 6 5 4 3 2 1
(1584-A)
DOWN STROKE

Fig. 50.

Two strainers are fitted, one for each pump, and as each pump is of sufficient capacity to lubricate the engine, either of the strainers may be removed for cleaning without affecting the running. A valve is fitted which automatically shuts off the oil from the pump when a strainer is removed, and so prevents grit being drawn into

the oil pipes if the engine is running when the strainer is taken out.

Fig. 49 shows a set of indicator diagrams taken at full load, while Figs. 50, 51, and 52 give a turning effort diagram and

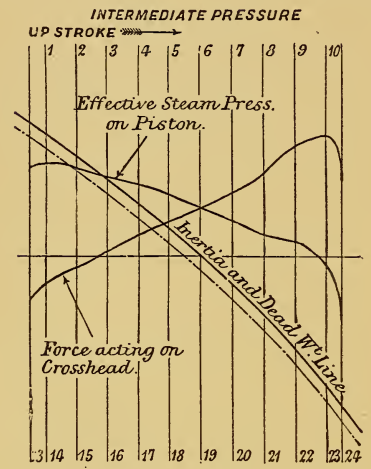


Fig. 51.

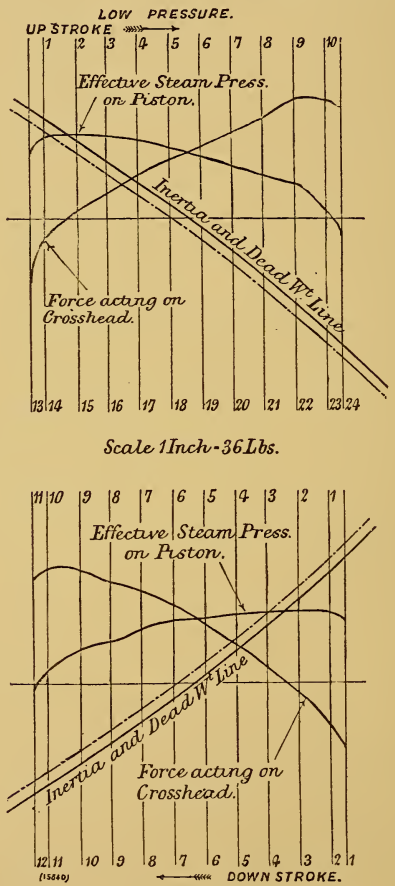

LOW PRESSURE.
UP STROKE
Effective Steam Press. on Piston.
Inertia and Dead Wt Line
Force acting on Crosshead.
Scale 1 Inch - 36 Lbs.
Effective Steam Press. on Piston.
Inertia and Dead Wt Line
Force acting on Crosshead.
DOWN STROKE.

Fig. 52.

curves of cross-head forces, which should be of interest. In Figs. 50, 51, and 52, the chain-dotted curves represent the inertia, while the full lines parallel to these curves represent the same thing with the addition or subtraction of the constant dead-weight.

Fig. 53 is a curve of the combined turning effort, in which the scale of lbs. is 1 inch to 80,000.

Scale of crank-pin travel $\frac{3}{4}$ inch = 1 foot.

Scale of tangential pressure = $\frac{\text{turning moments}}{\text{length of crank}}$ = 80,000 to 1 in.

Scale of work done = 80,000 ÷ $\frac{3}{4}$ = 106,666 foot-lbs. to each square inch of area enclosed by curve.

Fig. 54 is a curve showing the fluctuation of tangential pressures, the cyclical variation being 1 in 500.

Fig. 55 shows the general arrangement of the well-known Belliss and Morcom engine, and Fig. 56 gives the steam consumption guaranteed with the engines.

Fig. 57 shows some 1500 K.W. Belliss and Morcom sets installed at the Summer Lane Power House, Birmingham, England, in which there is a total installation of 25,000 B.H.P. These engines represent the highest and best practice, and are working in all parts of the world.

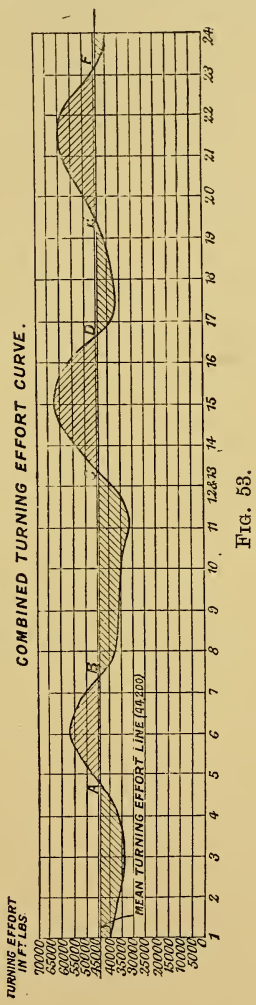


Fig. 53.

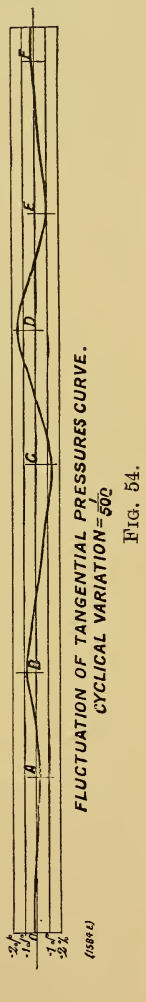


Fig. 54.

These sets have a continuous output of 1000 kilowatts, with a 25 per cent. overload for short periods of time running at 160 revolutions per minute, and using steam at 180 lbs. pressure. They have an output of 2140 B.H.P. normal, and 2680 B.H.P. maximum, the cylinder sizes being 25 inches, 36½ inches,

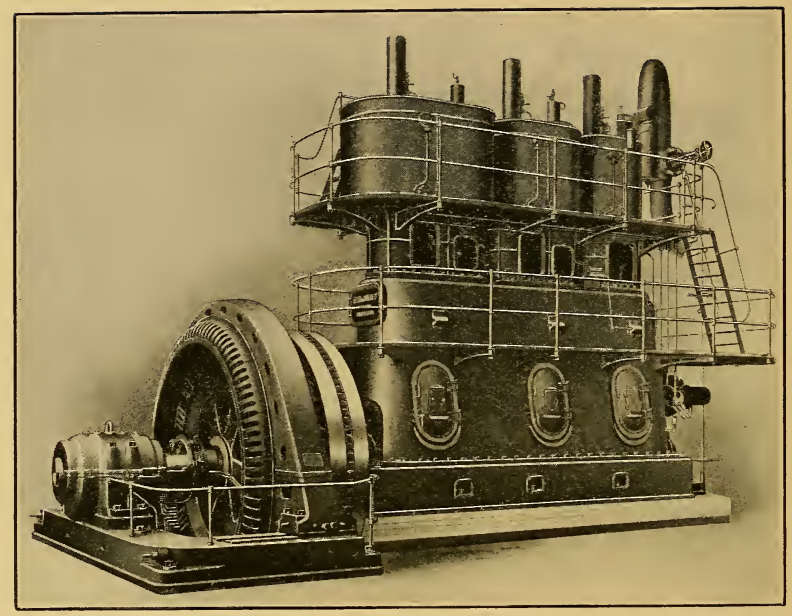


FIG. 55.

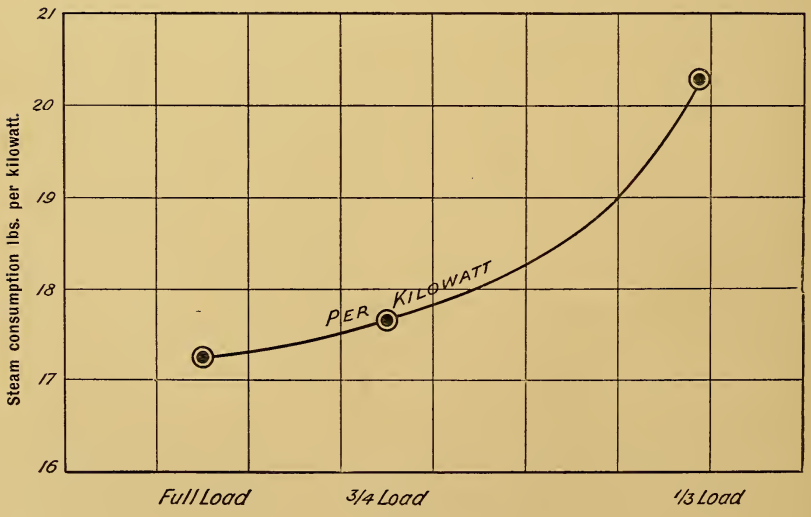

21
20
19
18
17
16
Steam consumption lbs. per kilowatt.
PER KILOWATT
Full Load
3/4 Load
1/3 Load

FIG. 56.

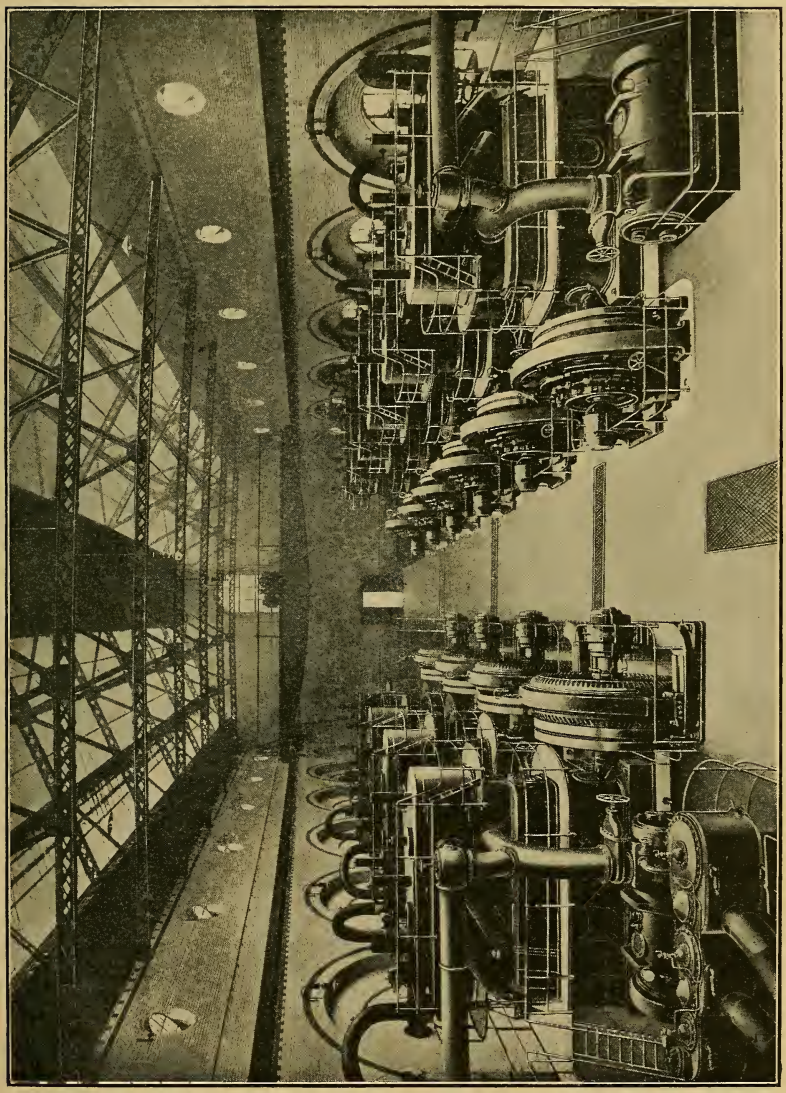


FIG. 57.

and 55 inches diameter by 33 inches stroke. Piston valves are fitted to all cylinders, the valve gear being of the single eccentric type. Automatic expansion gear is fitted to all the engines, the cut-off of the high-pressure slide valve being varied by means of a special relay cylinder, operated from the same governor as works the throttle-valve. On this plan the governing is by automatic expansion at the higher loads and by the throttle at the lower loads, an arrangement which experience has shown to give the most economical performance with high-speed engines.

Table No. XLVIII. gives the dimensions, weights, and approximate prices of standard high-class compound and tripal expansion engines. The prices given are of course only approximate and are covering prices for estimating purposes only.

TABLE XLVIII.

Approximate Dimensions and Weights of Two-crank Compound Double-acting, Quick-revolution, Forced-lubrication Engines.

Output kilowatts.	Length.	Width.	Height.	Weight.	Weight of heaviest lift.	Speed.	Approximate price engine only.
	ft. ins.	ft. ins.	ft. ins.	T. C.	T. C.		£
50	5 3	3 8	6 6¼	2 15	2 15	575/600	288
75	5 3	3 8	6 8¼	3 5	1 14	400/525	323
100	6 3½	4 2	8 3	5 10	2 15	475/500	388
150	7 2½	4 6	8 9	7 0	3 0	428/435	470
200	7 11	5 3	9 6	9 15	3 15	375	602
300	8 5¾	5 4½	10 0	12 12	4 0	375	721
400	8 11½	5 6¼	10 6	14 10	4 10	350/375	822

Approximate Dimensions and Weights of Triple Expansion, Double-acting, Quick-revolution, Forced-lubrication Engines.

Output kilowatts.	Length.	Width.	Height.	Weight.	Weight of heaviest lift.	Speed.	Approximate price engine only.
	ft. ins.	ft. ins.	ft. ins.	T. C.	T. C.		£
300	12 7½	6 0	10 10	17 8	5 5	375	1,069
400	13 5¾	6 0	11 7	23 3	6 15	375	1,284
500	14 8¾	6 6	13 9	29 2	7 10	333	1,593
750	18 5½	7 11	18 0	49 5	11 6	250	2,647
1000	20 11¼	7 6	18 7	68 7	12 0	250	3,903
1500	25 11	8 0	24 0	110 0	20 5	188	6,046

There are several practical points to be considered when specifying reciprocating engines for power-house work. The size being settled, the standard of speed is also settled to suit the frequency of the system if alternating current. The steam-range pressure will be probably fixed from 180 to 200 lbs., and a moderate superheat of, say, 100° Fahr. The principal details with which an engineer has to concern himself are:

(*a*) Steam consumption guaranteed, with which he will have no difficulty with any well-known maker.

(*b*) Weight of fly-wheel and rotor and guaranteed maximum limit of cyclic irregularity.

(*c*) Governor trials and freedom from hunting, so as to enable machines to be run in parallel without trouble. The maximum temporary increase or reduction of speed due to suddenly throwing off the whole load not to exceed 10 per cent. of the standard speed and the continuing alteration in speed not to exceed 5 per cent. The maximum temporary variation in speed due to the load being varied gradually, or by steps not exceeding 20 per cent. of the rated load, not to exceed 5 per cent. of the standard. A motor-driven speeding gear operated from switchboard is a good auxiliary.

(*d*) Duplicate oil pumps for the forced-lubrication system, a selection of a proper oil to suit the running conditions of the engine, and, if necessary, to adopt a water-circulating system for the crank chamber.

(*e*) Grouping of all gauges and drain handles at the driving end, so as to be accessible and under the view of the engine-driver.

(*f*) Suitability of white metal composition for the particular engine bearings and climatic conditions of running.

(*g*) Careful selection of the metallic packings for the piston and valve-rod stuffing boxes, and also of the piston rings—particularly the H.P. end.

(*h*) Fixing of suitable relief valves and cocks for indicator gear not only on the cylinders but also on the receivers.

(*i*) Suitable access platforms to the glands, and, if tail rods are used, to the cylinder tops also.

(*j*) Careful balancing of engine.

(*k*) Interchangeability of parts with sister engines. This is most important especially with regard to the stock of spare parts.

(*l*) The engine to be capable of driving the generator continuously at all loads up to the rated output, and also at 20 per cent. above rated output for a period of two hours, without undue heating of the bearings or other mechanical trouble.

Fig. 58 shows a correction curve for varying superheat. This curve is useful on steam trials to read off the percentage variation in steam consumption due to any variation in superheat.

In well-designed power houses the plant is so split up as to enable each set to be kept when running at as high a plant-load factor as possible. The result is a lower steam consumption. In small installations it is often worth while to graduate the sizes of the plant so as best to fit in with the variable load throughout the day. Thus, while eight sets of plant are an ideal number for large installations, there are, of course, many smaller cases where a less number is required, and then it is that graduated sizes should be adopted. The following Table, No. XLIX., gives a suggestive analysis of the sizes of plant which may be adopted, but must be taken with great caution, since each problem must receive careful and local consideration.

TABLE XLIX.

Total M.D. on power house.	Total K.W. installed.	Percentage of reserve plant.*	No. of sets.	Sizes recommended.
500	750	50	3 or 4	3×250 or $2 \times 125 + 2 \times 250$
1,000	1,500	50	5	$2 \times 250 + 2 \times 500$
2,500	3,500	40	5	$2 \times 250 + 3 \times 1000$
5,000	7,000	40	6	$2 \times 500 + 4 \times 1500$
10,000	12,000	25	7	$2 \times 1000 + 5 \times 2000$
17,500	20,000	25	8	8×2500

* Including 25 per cent. overload capacity in the larger sets.

It is impossible really to lay down any specific rule, because local requirements are so variable. The assumed daily load curve determines the proportion of small units to the large units installed, as will be seen by reference to Fig. 59, which shows a typical output curve for an English city.

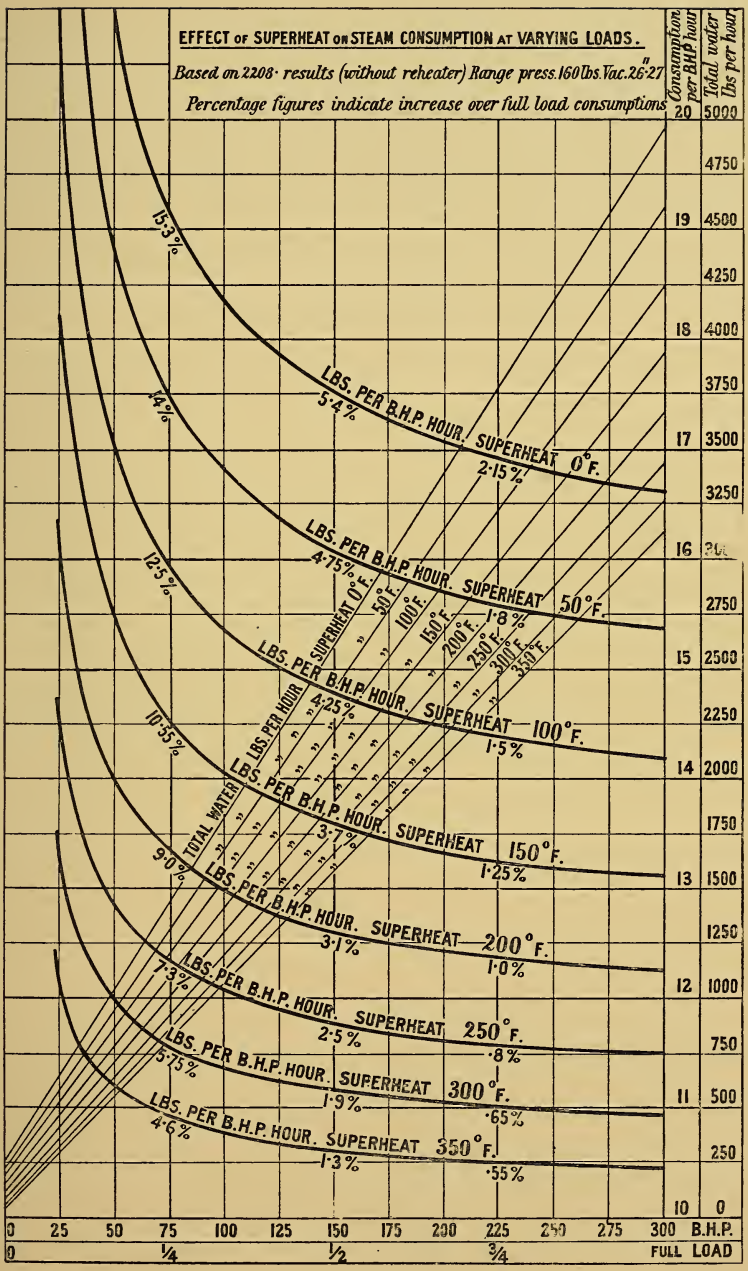

EFFECT OF SUPERHEAT ON STEAM CONSUMPTION AT VARYING LOADS.
Based on 2208 results (without reheater) Range press. 160 lbs. Vac. 26·27
Percentage figures indicate increase over full load consumptions
Consumption per B.H.P. hour
Total water lbs per hour
15·3%
14%
12·5%
10·35%
9·0%
7·3%
5·75%
4·6%
LBS. PER B.H.P. HOUR. SUPERHEAT 0°F.
5·4%
2·15%
LBS. PER B.H.P. HOUR. SUPERHEAT 50°F.
4·75%
1·8%
LBS. PER B.H.P. HOUR. SUPERHEAT 100°F.
4·25%
1·5%
LBS. PER B.H.P. HOUR. SUPERHEAT 150°F.
3·7%
1·25%
LBS. PER B.H.P. HOUR. SUPERHEAT 200°F.
3·1%
1·0%
LBS. PER B.H.P. HOUR. SUPERHEAT 250°F.
2·5%
·8%
LBS. PER B.H.P. HOUR. SUPERHEAT 300°F.
1·9%
·65%
LBS. PER B.H.P. HOUR. SUPERHEAT 350°F.
1·3%
·55%
SUPERHEAT 0°F.
50°F.
100°F.
150°F.
200°F.
250°F.
300°F.
350°F.
LBS. PER HOUR
TOTAL WATER
20
19
18
17
16
15
14
13
12
11
10
5000
4750
4500
4250
4000
3750
3500
3250
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
0 25 50 75 100 125 150 175 200 225 250 275 300 B.H.P.
0 ¼ ½ ¾ FULL LOAD

FIG. 58.

In direct-current power houses the supply would probably be by a 3-wire system. It is advisable to wind all the generators for the pressure across the outers, and to balance the system by a 3-wire balancer, and to charge batteries, if any, by motor-driven boosters. This removes the necessity of installing small generators at half pressure, *i.e.* that between an outer conductor and the neutral or middle wire. Still, however, in the generality of small plants, provision has to be made for very light night loads.

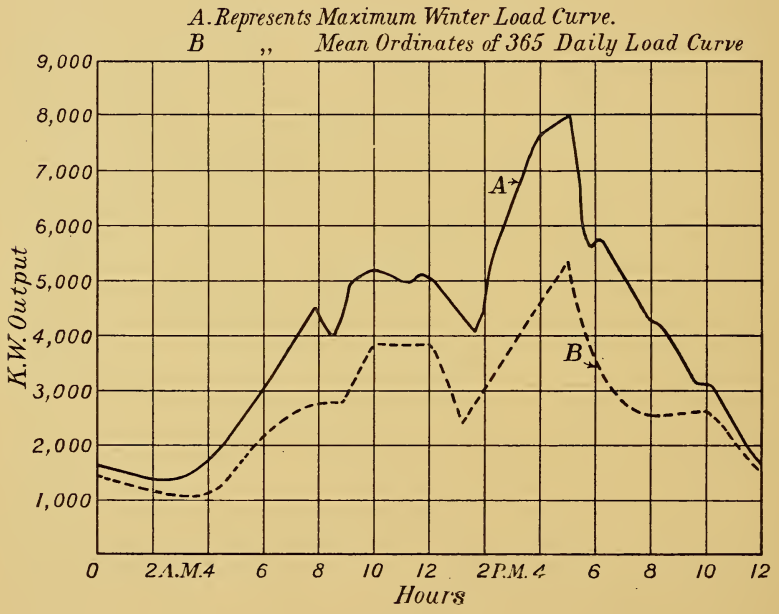


Fig. 59.

In the cases mentioned above, when the units are fairly well proportioned, so as to step up and down with the rising or falling load, then the most economical point in the steam-consumption curve should be arranged for the rated load. In well-designed throttle-governed, reciprocating engines, with an auxiliary variable cut-off, the steam-consumption curve is, however, fairly flat between $\frac{3}{4}$ load and $1\frac{1}{4}$ load.

Where, however, the load is continually varying, as in small

tramways, or a mine with winding sets and haulage, then it will be found that any given engine should be set so as to give the greatest economy at $\frac{3}{4}$ load, as that will be the average point at which it will run, the peaks taking the engine load up to the rated output or beyond.

The following figure (Fig. 60) is a typical curve of an ordinary tramway load, and shows that the mean load is only $\frac{5}{7}$ of the maximum peak recorded. Similarly, Fig. 61 shows the curve for an integrated daily load on a large system of mines to which the

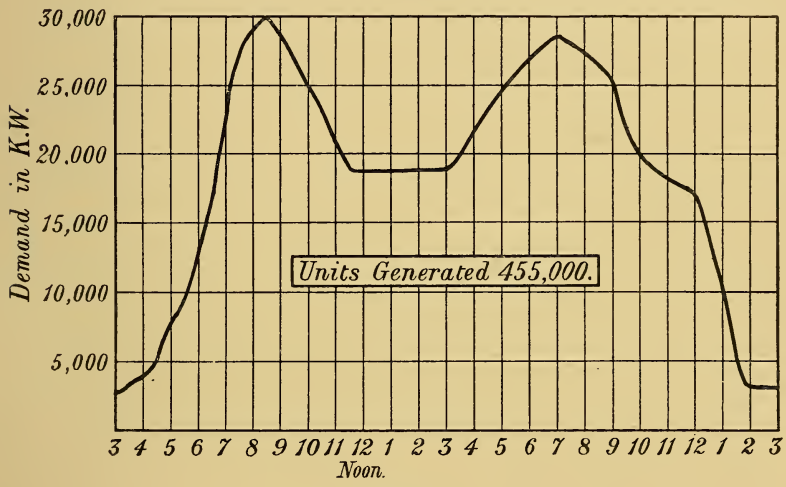


FIG. 60.

Author was adviser. In the former case the division of plant is as follows: Four sets each of 5000 K.W., and four sets each of 3500 K.W., making a total of 34,000 K.W. normal rating.

In the latter case the plant installed was three sets each of 1150 B.H.P. or 750 K.W.—a total of 2250 K.W.

Fig. 62 represents the results of some elaborate tests made by Messrs. Belliss and Morcom on a triple expansion engine to determine the effect of various degrees of superheat at various loads. The reduction in steam consumption due to the increase of superheat is shown, and also the flattening effect due to the superheat. At the time of these tests the engine was not fitted with the automatic expansion gear with which all the larger engines

made by this company are now fitted, otherwise the steam consumption at the various loads would have approximated more closely at the higher superheats than the curve shows them to do.

Fig. 62 shows the approximate full-load steam consumptions per K.W. hour for triple-expansion, double-acting engines, when exhausting into a condenser vacuum within 4 inches of the barometer.

The curves show the variation between no superheat and

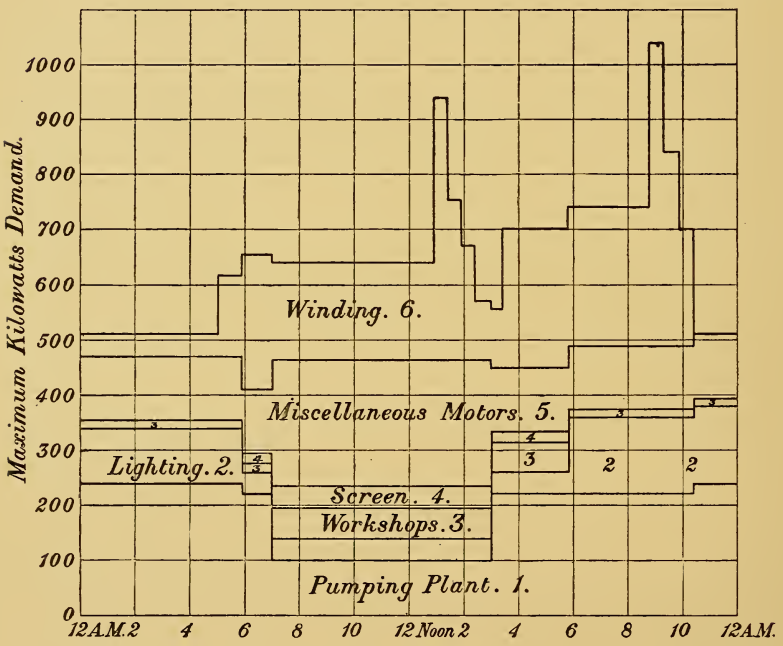


Fig. 61.

250° Fahr. superheat. A table is also appended to the figure, giving the correction for the fractional loads.

In order to obtain the approximate full-load steam consumption under non-condensing conditions, add 30 per cent. to the values given in the curves shown in Fig. 62.

The following Table, No. L., gives the approximate percentage increase at lower loads non-condensing.

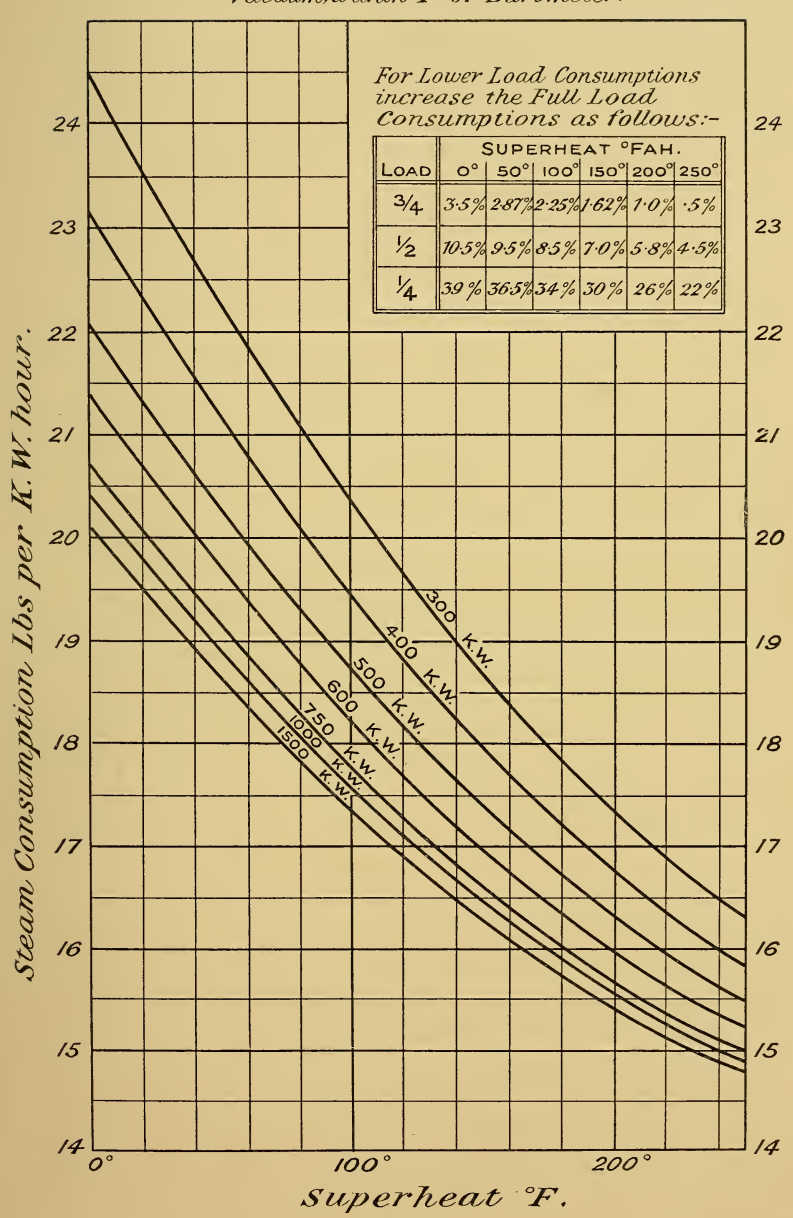

Steam Pressure, 180 lbs per O".
Vacuum, within 4" of Barometer.
For Lower Load Consumptions increase the Full Load Consumptions as follows:-
LOAD
SUPERHEAT °FAH.
0° 50° 100° 150° 200° 250°
3/4 3·5% 2·87% 2·25% 1·62% 1·0% ·5%
1/2 10·5% 9·5% 8·5% 7·0% 5·8% 4·5%
1/4 39% 36·5% 34% 30% 26% 22%
300 K.W.
400 K.W.
500 K.W.
600 K.W.
750 K.W.
1000 K.W.
1500 K.W.
Steam Consumption Lbs per K.W. hour.
24
23
22
21
20
19
18
17
16
15
14
0°
100°
200°
Superheat °F.

FIG. 62.

TABLE L.

PERCENTAGE INCREASE ON FULL-LOAD NON-CONDENSING FIGURES, SHOWING THE INCREASED STEAM CONSUMPTION AT FRACTIONAL LOADS NON-CONDENSING. FULL-LOAD STEAM PRESSURE FROM 150–180 LBS. PER SQUARE INCH.

Superheat (degrees Fahr.).	0°	50°	100°	150°	200°	250°
¾-load . . .	6·5	5·5	4·75	4·1	3·5	2·7
½-load . . .	20·5	19·0	17·5	16·0	14·0	12·0
¼-load . . .	76·0	71·0	65·0	58·0	50·0	41·0

Similarly, Fig. 63 shows the steam consumption per K.W. hour at full load of compound engines double-acting with an initial steam pressure of 150 lbs. per square inch, and under the same conditions of superheat and vacuum as the foregoing Fig. 62.

Turbines.—The development of turbines has been most rapid. Broadly they may be divided into three practical classes.

(*a*) The impulse type, such as the Curtis, Zoelly, Rateau, and others, with only a few stages of expansion.

(*b*) The reaction type, such as the Parsons and derivatives of that design, with fifty or more stages of expansion.

(*c*) A combination of an impulse or velocity wheel which reduces the initial pressure and temperatures approximately to those of atmosphere, and reaction blades for the remainder of the expansion, such as the Belliss and Morcom, Bergmann, Willans, etc.

In the impulse type the steam is admitted to the turbine through expanding nozzles, and on leaving the directing nozzle impinges on specially shaped buckets fixed on a revolving disc or wheel. The various types, which are variables of design and not of principle, will be briefly described hereunder.

In the reaction type the steam is admitted at the H.P. end through fixed vanes, which guide the steam in the right direction so that it flows through properly inclined blades fixed on the turbine rotor. The size and clearances of the vanes and blades increase towards the exhaust end as the pressure of the steam

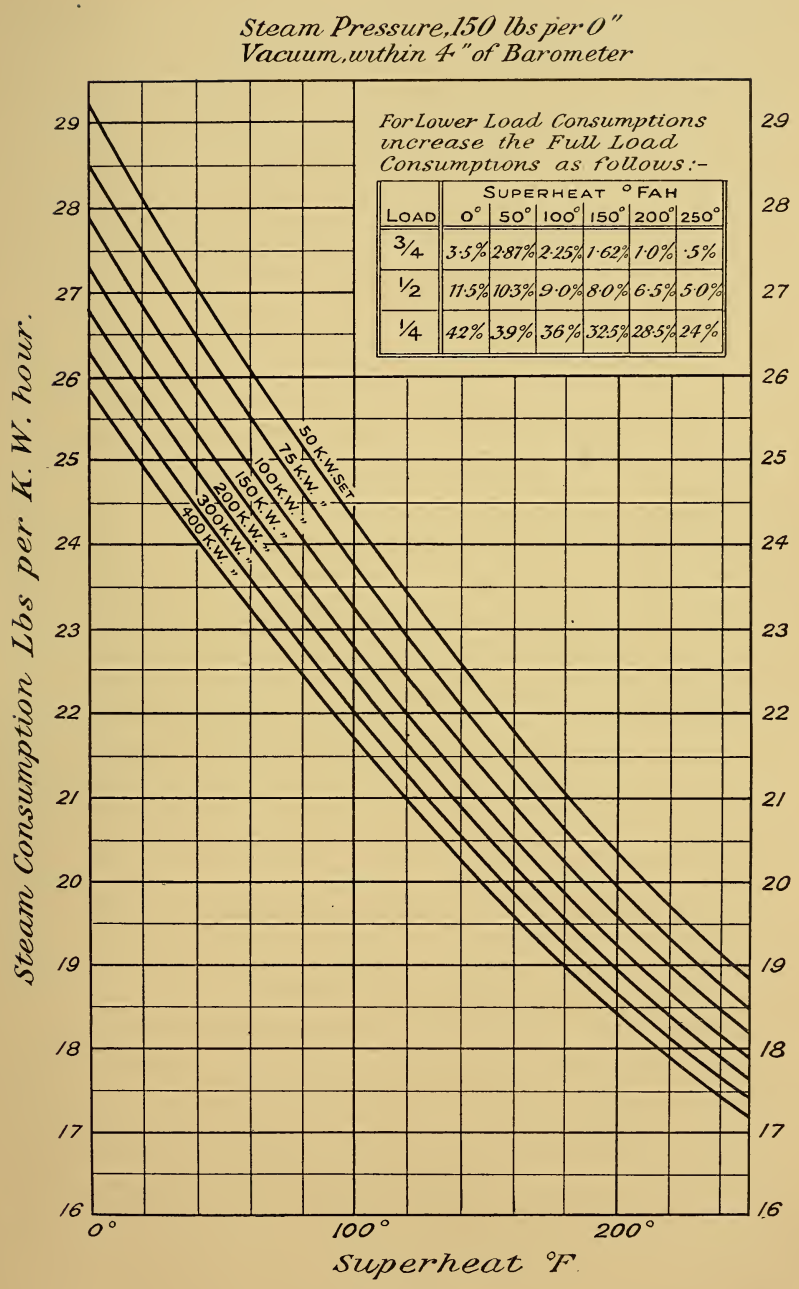

Steam Pressure, 150 lbs per 0"
Vacuum, within 4" of Barometer
For Lower Load Consumptions increase the Full Load Consumptions as follows:-
Load | Superheat °Fah 0° | 50° | 100° | 150° | 200° | 250°
3/4 | 3·5% | 2·87% | 2·25% | 1·62% | 1·0% | ·5%
1/2 | 11·5% | 10·3% | 9·0% | 8·0% | 6·5% | 5·0%
1/4 | 42% | 39% | 36% | 32·5% | 28·5% | 24%
50 K.W. Set
75 K.W. "
100 K.W. "
150 K.W. "
200 K.W. "
300 K.W. "
400 K.W. "
Steam Consumption Lbs per K. W. hour.
29
28
27
26
25
24
23
22
21
20
19
18
17
16
0°
100°
200°
Superheat °F.

FIG. 63.

decreases and the volume increases. In some cases, as in the Westinghouse, steam is admitted in the middle of the turbine and flows right and left to the L.P. ends, giving what is known as a double flow, balancing the turbine, and thus removing end thrust. In the single flow turbines this end thrust has to be compensated for by dummy pistons, against which live steam impinges. In this type the clearances are very minute, and great care has to be exercised when warming or running up any set, so as to prevent one side getting more heat than the other, and thus causing deformation in the rotor spindle.

Economy of Turbines.—The economy of turbines is threefold: first, the steam consumptions are as good as, or better than, any of the best reciprocating sets, and no oil is required in the turbine cylinders; secondly, their capital cost above 750 K.W. is increasingly less as their size increases; thirdly, the floor space occupied is also smaller, entailing less cost of buildings and foundations.

It must, however, be borne in mind that the economy of a turbine is entirely dependent on the maintenance of a good vacuum, and the cost of a larger condenser has to be included together with a more liberal allowance of circulating water.

Effect of Superheat on Turbines.—Experiments made by Mr. G. Stoney, on a Parsons turbine, at Elberfeld, show a gain of 1 per cent. economy in steam consumption for every 6·8° C. (12·2° F.) increase of superheat.

Effect of Vacuum on Turbines.—In tests made on a Parsons turbine, at Cheltenham, a reduction of the back pressure from 0·46 lb. to 0·25 lb. absolute, showed a saving in steam consumption of 8·95 per cent., the theoretical gain being 12·4 per cent. On still further decreasing the back pressure to 0·22 lb., a further gain of 4·65 per cent. was made.

Thus, especially in the smaller plants, and more especially where auxiliary cooling towers have to be adopted, it is fair to compare not the prices and performances of engine or turbine alone, but each with its added condenser and condenser auxiliaries. More will be said about this in the condenser section. (See also Fig. 85.)

Table No. LI. gives a list of the principal types of turbines, with particulars of sizes and speeds.

TABLE LI.

COMPARATIVE TABLE OF STEAM TURBINES.

Type.	Class.	Output.	Speed.	Peripheral speed in feet per second.	Expansion stages.	Total number of rows of blades or wheels.	Characteristics.
Parsons	Reaction	1500	1200	100–220	Continuous	78	Drum construction, fall of pressure equally divided between fixed and moving blades.
Rateau	Impulse	1500	1200	150–250	25	25	Disc construction, fall of pressure only at nozzles in fixed diaphragms.
Curtis	do.	1500	1000	400	4	8	Disc construction, two rows of revolving blades to each set of expanding nozzles.
Zoelly	do.	1500	750	275	20	20	Disc construction, fall of pressure only at nozzles in fixed diaphragms.

In alternating work a frequency of 50 ~ fixes the speeds at 750, 1500, or 3000 R.P.M. for 8, 4, and 2-pole generators respectively, and a limiting speed of 1500 R.P.M. is not exceeded in generators over 1500 K.V.A., or 750 above 3000 K.V.A.

It is true that manufacturers are prepared to supply 2500 K.V.A. sets at speeds of 1500 R.P.M., the peripheral speed of the rotor being about 22,000 feet per minute. In large sets of 5000 K.V.A. and over, the peripheral speed is usually about 17,000 feet per minute (285 feet per second). Any increase above this figure must obviously reduce the factor of safety in the ultimate strength of the revolving materials and, in the Author's opinion, is inadvisable.

The following descriptions of the principal types will be useful to the designer. For more detailed information reference should be made to the various well-known books on the Steam Turbine, such as those by Jude, Stodola, and others.

Impulse Turbines.—The advantages of impulse type turbines are the greater mechanical strength of construction, and the greater

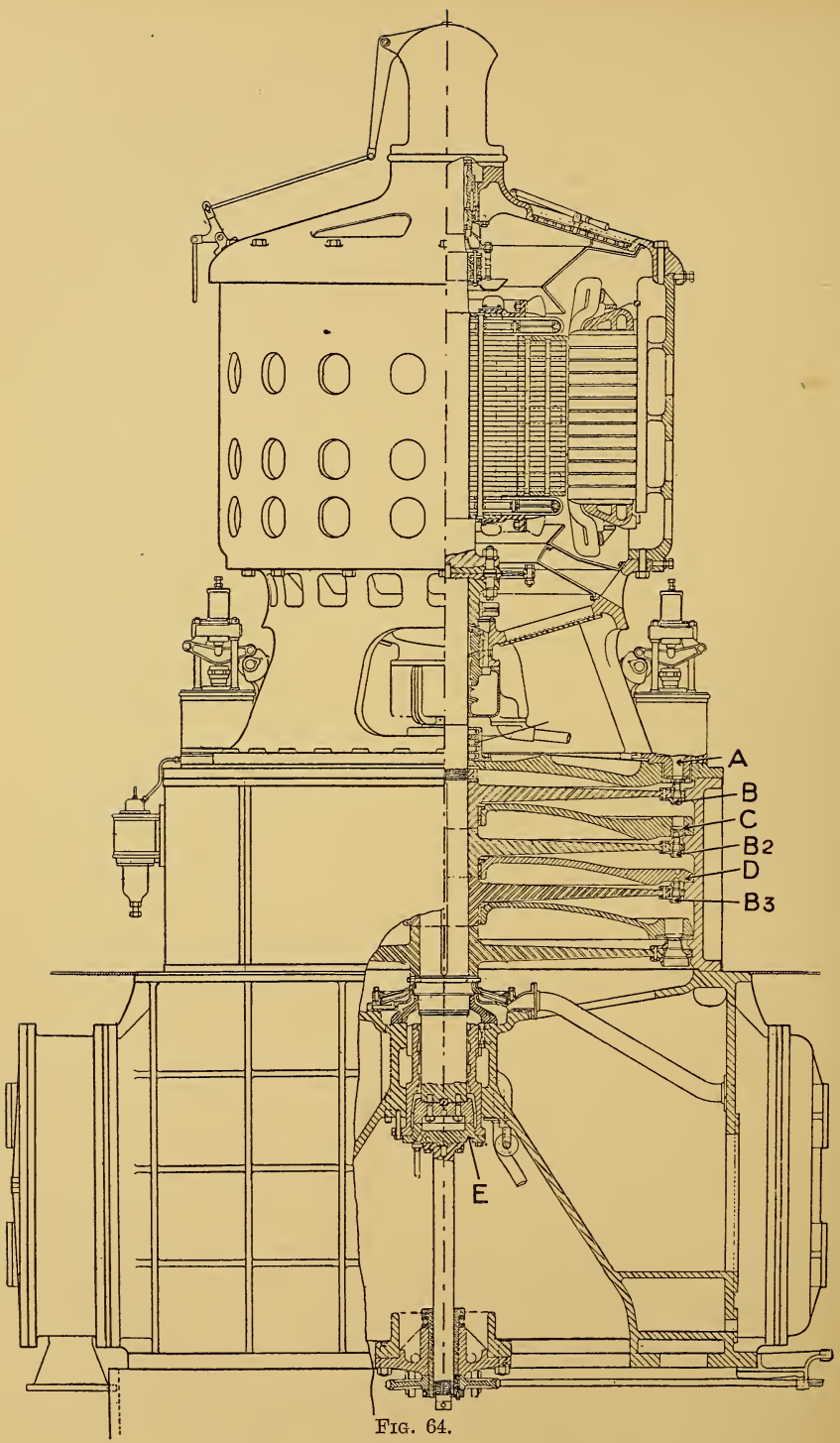


FIG. 64.

clearances of rotating parts. For large sizes there can be little doubt that this type will outlast the reaction type as now built, and presently to be described. The peripheral velocity can be kept within safe limits by increasing the number of wheels, and the steam curves are as good as that obtained by the other type. Great care has to be exercised in proportioning the sections of the rotating masses, and the greatest precision can be made in the accurate machining and fitting of the buckets to their discs and in the balancing of each wheel. On such big circumferences the

Fig. 65.

marking off has to be of the most precise kind, so as to obtain a nicety of balance.

Curtis Turbines.—The Curtis turbine is made by the General Electric Co. at Schenectady in America, the B. Thomson Houston Co. in Great Britain, and the A. E. G. in Germany. These turbines are made to run both on a vertical axis as shown in Fig. 64, and also on a horizontal axis as shown in Fig. 65.

A reference to Fig. 64 shows the general construction and principle of this turbine. Steam is admitted by a number of poppet valves as shown at A, which open successively as the load increases; it is then delivered in an axial direction and impinges

on the first line of buckets, B, milled out of and carried on a steel disc increasing in thickness towards the hub. After passing through B it is passed through a fixed series of guides, C, to a second line of buckets, B_2, thence through a third series of guides, D, to a third line of buckets, B_3. The kinetic energy only of the steam is utilized, the flow through the buckets being maintained at constant pressure. There is thus an equilibrium of pressures on both sides of the rotor-disc. The velocity of the steam, of course, decreases at each stage. The curve shown in Fig. 66 is a

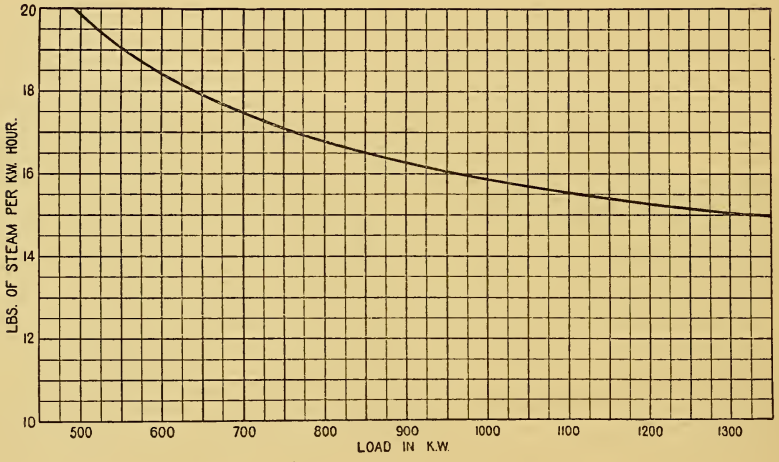


FIG. 66.

typical steam consumption curve for a 1000-K.W. Curtis set, the initial steam pressure being 160 lbs. per inch, the superheat 100° F. (total temp. 470° F.) and vacuum 27 inches. In the vertical type a foot-step bearing, E, is introduced with oil or water under a pressure of 500 lbs. per square inch. The objection to the vertical type lies in having to dismantle the generator above it in the event of any accident to the turbine discs, and also from possible escape of steam through the H.P. gland. The Curtis turbine normally works at a peripheral speed of 400 feet per second.

The following Table, No. LII., gives some tests of Curtis turbines taken at various power houses in America and in England.

TABLE LII.

Rating.	Test taken at	Test load.	Steam.		Vacuum 30-inch barometer.	Steam consumption per K.W. hour.
			Pressure	Superheat.		
K.W.		K.W.	lbs.	deg. Fahr.	ins.	lbs.
8000	Chicago, Fisk Street .	5,309	180	136	28·21	14·95
		8,191	184	143	29·44	12·68
		10,156	176	147	29·50	12·94
		12,108	182	148	29·34	13·05
		14,132	194	150	29·31	13·13
5000	Boston . .	5,195	174	142	29·3	13·52
		7,526	170	134	28·6	13·73
4000	Rimmelsburg	4,239	180	280	29·2	11·9
		2,236	184	270	29·4	11·7
2500	South Wales	2,497	126	68	28·4	16·06
		1,266	132	67	28·2	18·67
1000	Lancashire Tramways	1,004	153	100	28·88	15·9
		1,250	148	145	28·77	15·2

Zoelly Turbines.—The Zoelly turbine made by Messrs. Escher, Weiss and Co. of Zurich, and by Messrs. Howden and others in Great Britain, is another multiple stage impulse type. Guide blades of steel, as shown at A in Fig. 67, are fixed on the periphery of the fixed disc, and are held in position by rings B and C. The steel impulse wheels are made with a slot into which the polished blades are accurately machined to fit, and a shrouding ring is fitted when the blades have been fixed in position and permanently riveted up.

Fig. 67 shows a 6000-K.W. Zoelly turbine supplied in 1909 to the Stuart Street Power House at Manchester, England.

The turbine is sub-divided into twenty stages and the steam expanded from stage to stage. Since the velocity of the steam only is used in the moving blades, a greater clearance can be employed between the fixed and moving parts, the radial and axial clearance in this turbine being $\frac{3}{16}$ inch (5 mm.). As the pressure is reduced through expansion, the number of blades has, of course, to be increased, and thus the L.P. discs are larger in diameter. A typical guide wheel is shown in Fig. 68; this is made in halves so that the upper portion of the guide wheel can be removed with

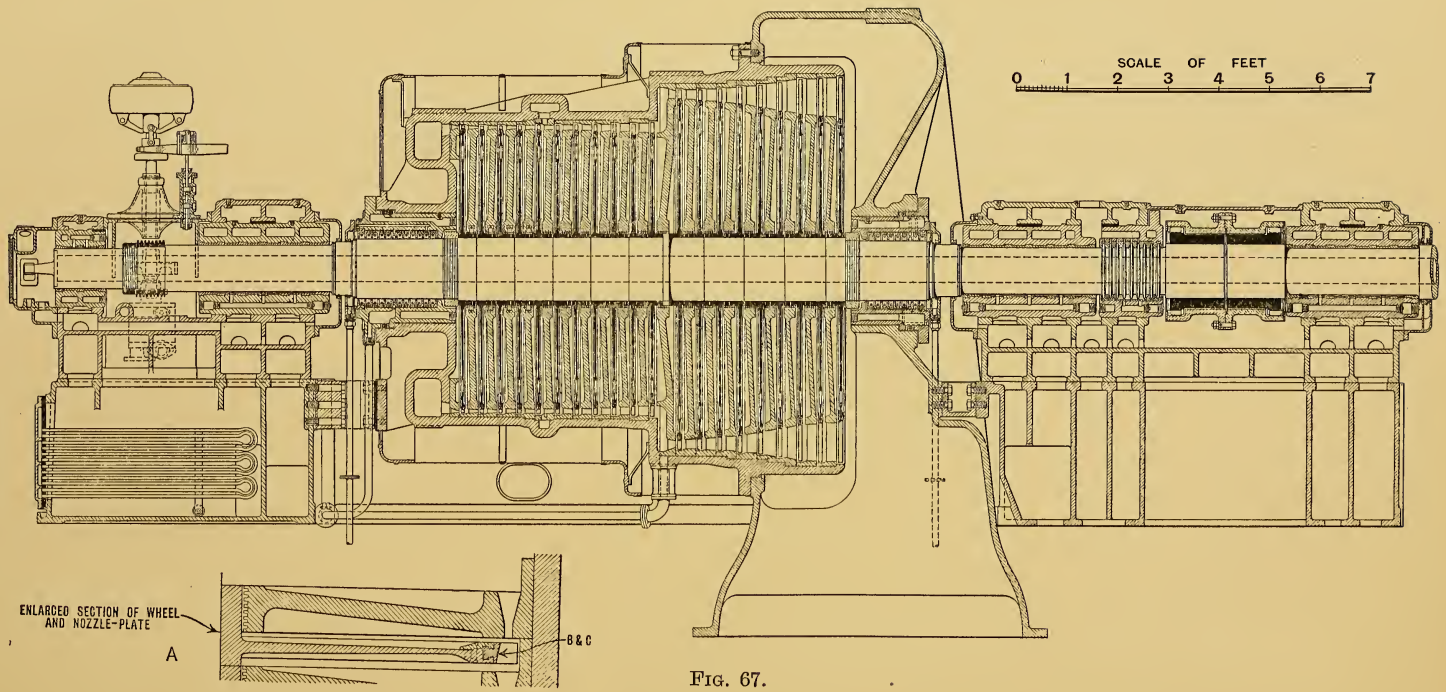

SCALE OF FEET
0 1 2 3 4 5 6 7
ENLARGED SECTION OF WHEEL AND NOZZLE-PLATE
A
B&C

FIG. 67.

the upper half of the turbine casing. A bye-pass is fitted by which H.P. steam can be admitted to the lower stages if an emergency load is required, and it is thus possible to increase the turbine load to 10,000 K.W. if necessary. Without this bye-pass the turbine will develop 8000 K.W. The following advantages are claimed by the makers:—

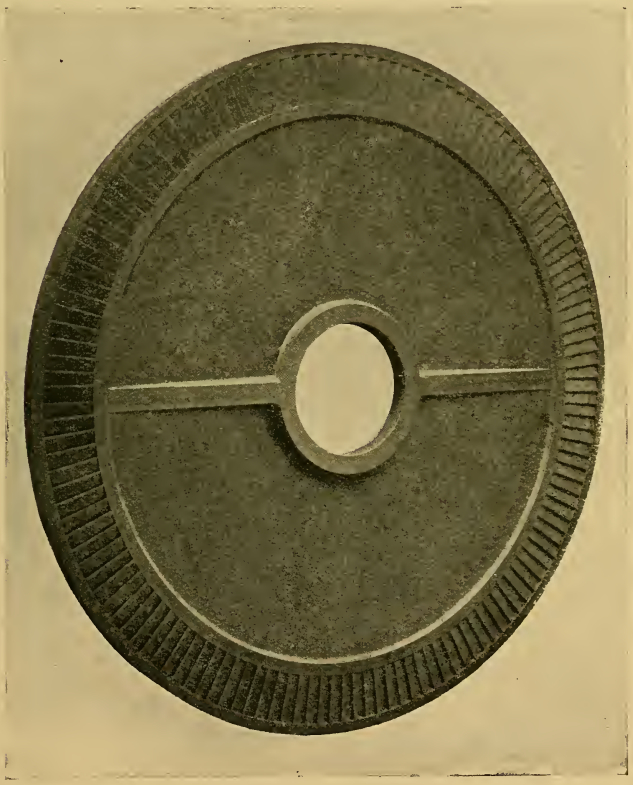


Fig. 68.

(*a*) The turbine has only from $\frac{1}{3}$ to $\frac{1}{5}$ of the number of blades of all ordinary multistage reaction turbines, giving the same power and at the same speed.

(*b*) The average velocity of the steam being low (280 feet per second) the wear in the blades is practically negligible.

(*c*) Ample clearance between all fixed and movable parts.

(*d*) No adjustment is thus necessary either in the thrust or in the main bearings.

(*e*) As the principle involved in the design eliminates all axial thrust, balancing pistons are avoided, and the leakage resulting from such pistons is eliminated.

(*f*) Owing to the form of casing adopted, the greatest advantage can be obtained from high superheat without danger from warping, and it is claimed that the turbine can be worked satisfactorily with temperature as high as 700° Fahr.

(*g*) The lubrication is entirely automatic.

(*h*) The governing is exact and instantaneous, since the steam is not admitted in gusts, and thus paralleling of alternators is rendered thoroughly easy.

(*i*) Each rotating wheel is separately balanced. After erection the whole rotor is balanced, therefore there is no vibration.

(*j*) The steam consumption does not increase after running for a length of time.

The steam consumptions on the official trials conducted by Mr. S. L. Pearce were as follows in Table No. LIII.

TABLE LIII.

Col. No. I. Guarantee 27″ Vac. Bar. 30″ Total Steam Temp. 523° Fahr.
,, II. do. 28″ ,, ,, ,, ,, ,, ,,
,, III. Official test 27″ ,, ,, ,, ,, 514°–532° ,,
,, IV. do. 28″ ,, ,, ,, ,, ,, ,,
,, V. Column IV. corrected to ,, ,, 523° ,,
,, VI. Alternator efficiencies,
,, VII. Thermodynamic efficiencies.
,, VIII. Column IV., including auxiliaries and excitation, but with allowance for inefficiency of step-down transformers and exciters.

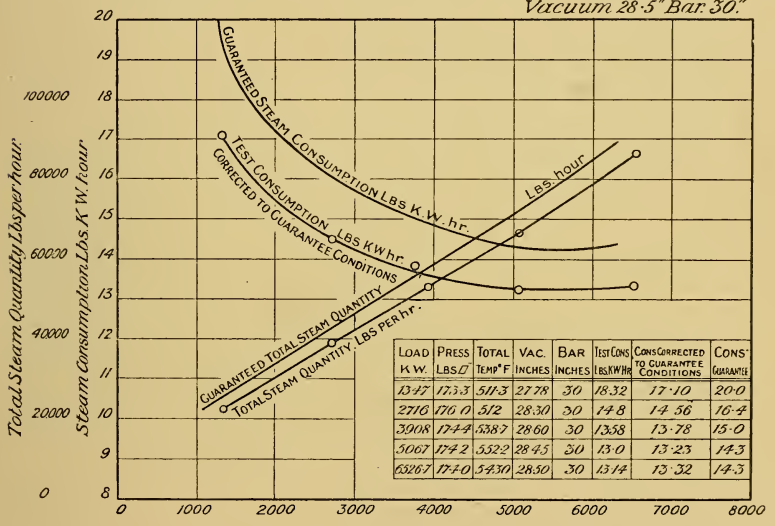
	Col. I.	Col. II.	Col. III.	Col. IV.	Col. V.	Col. VI.	Col. VII.	Col. VIII.
	lbs.	lbs.	lbs.	lbs.	lbs.	per cent.	per cent.	lbs.
25 per cent. overload	15·1	14·4	14·9	14·2	14·1	96·4	70·0	14·96
Rated load . .	14·4	13·7	14·6	13·9	13·8	96·4	71·5	14·83
Three-quarter load	15·4	14·6	15·0	14·3	14·4	95·1	69·4	15·57
Half-load . .	16·7	15·9	15·9	15·1	15·2	93·0	67·8	16·98
Quarter-load .	19·8	18·8	17·5	16·7	16·7	87·5	64·5	20·96

nickel bars, and their accuracy of machining has been carefully worked out.

The guide blade groups are arranged in a helical form, so that the steam may follow a natural path due to its velocity. This is an impulse type having a series of wheels fixed on a shaft and increasing in diameter with the various stages of expansion. The guide blades are fixed into steel division walls or diaphragms. The pressure is the same on both sides of any wheel, so that the axial thrust is very small.

5000 K W High Pressure Turbine, 1500 R.P.M.

Guarantee Conditions:-Steam Press 175 lbs. □g Total Temperature 527°F.
Vacuum 28·5" Bar. 30".


Total Steam Quantity Lbs per hour
Steam Consumption Lbs K W hour
Guaranteed Steam Consumption Lbs K W hr.
Test Consumption Lbs K W hr. Corrected to Guarantee Conditions
Lbs. hour
Guaranteed Total Steam Quantity
Total Steam Quantity Lbs per hr.
Useful Output in Kilowatts.

Load K W.	Press Lbs □"	Total Temp° F	Vac. Inches	Bar Inches	Test Cons Lbs K W Hr	Cons Corrected to Guarantee Conditions	Cons Guarantee
1347	171·3	511·3	27·78	30	18·32	17·10	20·0
2716	176·0	512	28·30	30	14·8	14·56	16·4
3908	174·4	538·7	28·60	30	13·58	13·78	15·0
5067	174·2	552·2	28·45	30	13·0	13·23	14·3
6326·7	174·0	543·0	28·50	30	13·14	13·32	14·3

FIG. 70.

These turbines generally are designed to work with a steam pressure of 180 lbs. at the stop valve, total temperature of steam 500° Fahr., and a vacuum equivalent to 95 per cent. of the barometric pressure, as above stated in the case of the L.C.C. machine. The speed being only 750 R.P.M., of course involves more wheels of a larger diameter than would be the case with sets running at 1000 or 1500 R.P.M. In turbines of this class, running at 1500 R.P.M., there are only half the number of wheels, and these are necessarily of much less diameter. The steam

consumption of low-speed turbines is also necessarily greater than that of high-speed sets, and the capital cost is also greater.

Fig. 70 shows the guaranteed and the test figures of steam consumption for a 5000-K.W. Westinghouse Rateau turbine running at 1500 R.P.M.

The construction of the impulse wheels of this turbine as made by the British Westinghouse Co., is beautifully worked out. Fig. 71 shows a group of fixed diaphragms and impulse wheels. B shows the guide blades fixed on a portion of the circumference, and they increase from stage to stage until the blades are fixed throughout the circumference, as shown at A. The diaphragms are fixed in circumferential grooves machined in the interior of the turbine casing, and are made of cast iron, divided along the horizontal diameter; special provision being made to prevent leakage along the shaft from stage to stage. The guide blades are of nickel steel, specially machined to the correct theoretical angle.

The impulse wheels are very thoroughly made, being forged from a high-class steel in one piece with the hub, very carefully turned, and so proportioned to the stresses that the factor of safety is never less than five. The blades are either fixed, as shown at D, or as shown at E. A steel shrouding band is riveted solidly to each blade, and as the steam pressure, as in all impulse turbines, is the same at both sides of the wheel, a radial clearance of 0·2 or 0·3 inch can be given between the casing and outer face of the shrouding. Each blade is very accurately machined to standard jig and checked with the greatest precision, and can either be slipped over the end of the wheel in a forked manner, as shown at E, or into a T-shaped groove, as shown at D. In the former case each blade is riveted, the discs or blades having been previously accurately drilled in special machines, the whole wheel being then accurately turned up and balanced. Fig. 72 is a view of a completed half-wheel.

Reaction Turbines.—The reaction type turbine, *i.e.* that in which the pressure at the entrance to the rotating wheel is greater than the pressure at the exit side, is the well-known Parsons turbine. This type is a multiple stage, and the clearances have to be very small indeed, to keep down leakages and to induce economy of steam consumption. The blades are made from drawn bronze

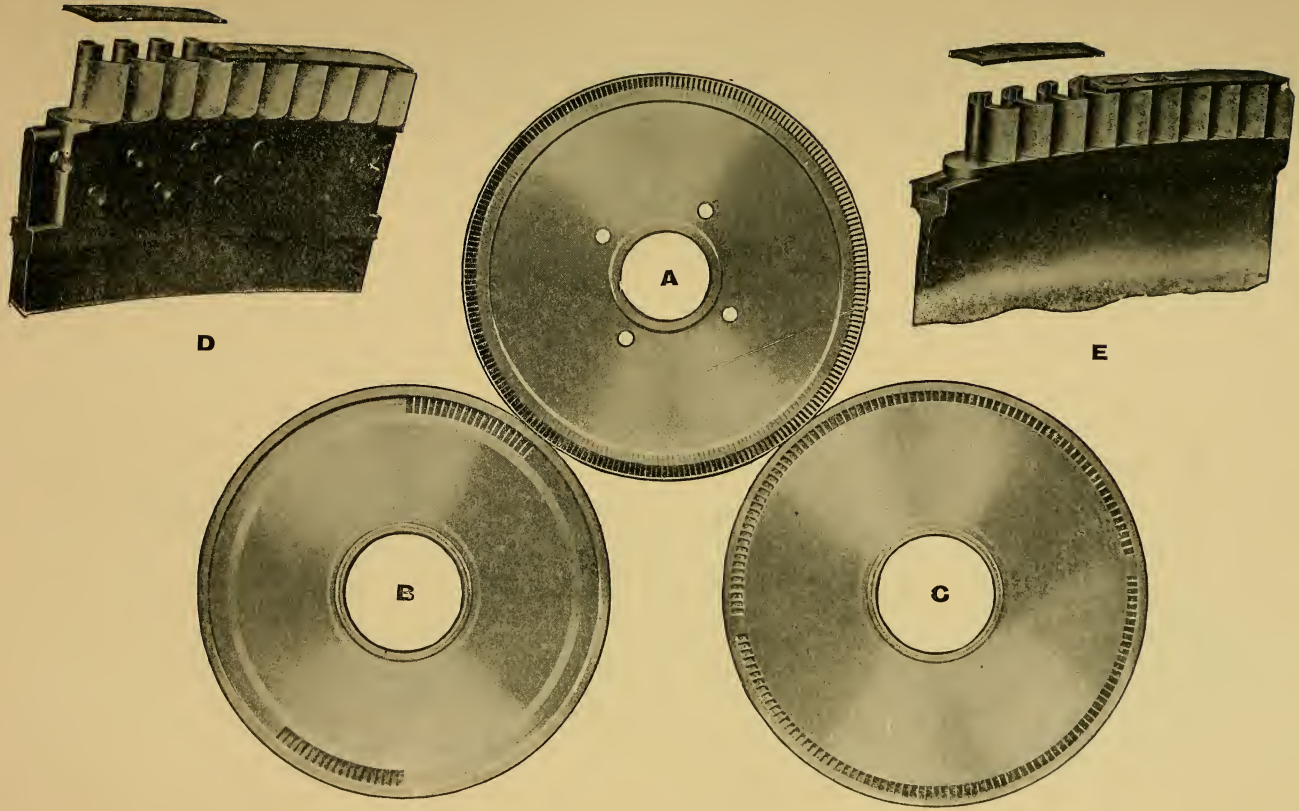


FIG. 71.

placed in grooves on the wheel, or in the casing, and caulked in position by small pieces of the same metal. The ends of the blades are usually fitted with a shrouding ring. Only very minute clearances are permissible, *e.g.* 35 mils. radially and 64 mils. horizontally at the H.P. stage in a 5000-K.W. set. The stuffing boxes are formed by labyrinth glands made up of a number of rings with alternate fine and coarse clearances. Balancing pistons have, of course, to be adopted to neutralize the end thrust on the turbine due to the differences in the pressure on successive faces of each wheel. The shafts are necessarily long in these turbines when of large powers, so that with the fine clearances necessary to good economy of steam consumption very great care has to be exercised in designing the proportions of the shaft, in balancing the rotor accurately, and in warming up the turbine so as not to get unequal expansions in the rotor.

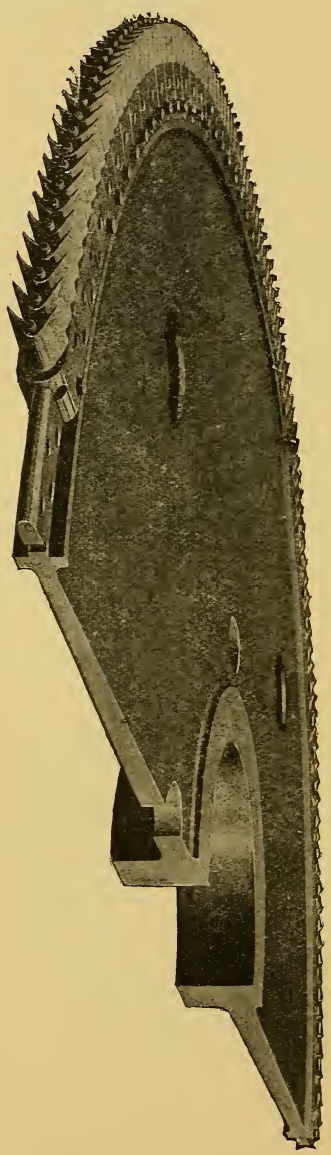


FIG. 72.

A micrometer test taken on a reaction turbine when cold, and during every succeeding 10 seconds while the turbine was being warmed up, from which a curve was drawn, showed the maximum distortion of the shaft from the centre to be 27 mils. So that the slow warming up causes the rotor to take up different positions in respect of its axis, and if the rotor be started up while distorted,

due to a difference of temperature between the top and bottom of the casing, stripped blades and a want of running balance will be the probable results. The best way to start up a reaction-type turbine is to close the emergency valve, and to get a fair pressure behind it, then, on lifting the valve suddenly, a puff of steam is taken into the turbine which is thus started up at once. The turbine should then be run dead slow for several minutes so that the rise in temperature may be evenly distributed, after which it can be run up to load. The superheat has to be carefully regulated so as to preserve a uniform temperature during any run.

The following Table, No. LV., sets out the result of tests made on reaction turbines of various sizes and makes.

Fig. 73 shows a curve taken from a 5000 to 6000 K.W. Willans-Siemens set. The actual readings have been corrected for a total superheat of 100° Fahr. and a vacuum of 27 inches. The steam consumptions do not include either the power required to drive the air and circulating pumps or the excitation losses. The lowest consumption on a net load of 5650 K.W. was 15·84 lbs. per K.W. hour.

TABLE LV.

Rating.	Steam pressure.	Superheat.	Vacuum 30″ Bar.	R.P.M.	Test load.	Steam consumption per kilowatt-hour.
K.W.	lbs.	deg. Fahr.	inches.		K.W.	lbs.
500	142	102	26·66	3003	517	20·15
1000	113	152	27·90	—	1000	17·0
1500	207	66	26·46	1208	1513	18·23
1500	129	125	27·52	1500	1585	17·60
3000	138·5	235	27·00	1350	2995	14·74
3500	199	150	29·12	1200	3500	15·64
5000	194	149	28·60	1200	5000	15·72

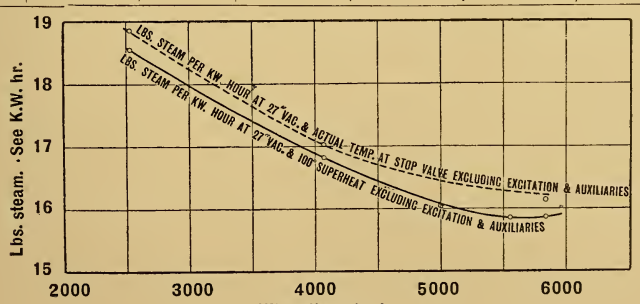


FIG. 73.

TABLE LVI.

ALTERNATING CURRENT GENERATORS.

Output.	Speed.			Overall dimensions of turbo-alternator.			Total weight of turbine.	Total weight of turbine and surface condenser.	Approximate cost of turbo-alternator and surface condenser and pumps.	
	~ 25	~ 50	~ 60	Length.	Width.	Height.				Per K.W.
K.W.				ft.	ft.	ft.	tons.	tons.	£	£
250	—	3000	3600	17·0	5	4·5	8	13	2250	9·00
500	1500	3000	3600	20·75	5·16	4·66	11·5	20	3250	6·50
750	1500	3000	1800	—	—	—	15·5	26	3800	5·06
1000	1500	3000 / 1500	1800	26·0	6·33	5·5	24	37	4850	4·85
1500	1500	1500	1200	28·5	6·33	6·66	36	53	7300	4·86
2000	1500	1500	1200	30·5	6·33	6·83	41	62	8650	4·32
3000	1500	1500	1200	33·0	6·33	8·0	—	—	—	—
4000	750	1000 / 750	1200	—	—	—	—	—	—	—
5000	750	1000 / 750	1200	36·5	9·16	9·25	—	—	—	—
7500	750	1000 / 750	900	42·0	9·16	9·5	—	—	—	—
10,000	750	750	720	—	—	—	—	—	—	—

Table No. LVI. gives the standard sizes, speeds, weights, by the Parsons type, as made under licence by Messrs. Willans & Robinson, Rugby, England.

Similarly Table No. LVII. sets out the leading particulars of reaction-type turbines coupled to direct current generators.

TABLE LVII.

DIRECT CURRENT GENERATORS.

Output.	Speed.	Overall dimensions.				Total weight. Turbine dynamo.	Total weight. Turbine dynamo and condenser.	Approximate cost of turbo-single generator and surface condenser.	
		Length. Single generator.	Length. Tandem generator.	Width.	Height.				Per K.W.
K.W.	R.P.M.	ft.	ft.	ft.	ft.	tons.	tons.	£	£
250	3000	20	27·5	5	4·5	7	13·5	2450	9·80
500	2500	22	30·5	5·16	4·66	13	23·0	4050	8·10
750	1850	—	—	—	—	20	33·0	4750	6·33
1000	1450	29·5	40·0	6·33	5·5	24	40·0	5750	5·75
1500	1000	30·5	44·0	6·33	6·66	35	55·0	8050	5·36

Combined Impulse and Reaction Turbines: "Disc and Drum."—An excellent compromise can be made by introducing a combination

of the impulse and reaction types, as in the Bergmann turbine (many other makers have adopted the same principle, of course, such as the Westinghouse, Brown Boveri, Willans & Robinson, and others). There is a velocity wheel, which reduces the admission pressure through nozzles to a figure only a little above the atmospheric pressure, whence the energy is further utilized by expanding through a series of reaction stages to the final exhaust pressure. In this way large ranges of temperature are removed from the turbine casing and the consequent stresses due to expansion and contraction are reduced to a minimum.

The weak point in reaction turbines of the Parsons type is the high-pressure blading, where the clearances are very small, and as the leakage at this point must be kept down, there is greater risk of fouling, and consequent stripping of the blades with a possible further trouble of shaft distortion. At the low-pressure end the clearance is only a small proportion of the blade area, and thus the clearance can be made large enough to prevent fouling without appreciable leakage losses.

Willans & Robinson make a turbine which eliminates this danger, known as the Impulse "disc and drum" type. There is a single-impulse wheel, without any shaft glands which constitutes the high-pressure end of the turbine, and this is fixed directly to the low-pressure part of the turbine; the low-pressure end being the usual reaction type. Thus, there are large clearances throughout the turbine, and the danger of fouling and stripping is minimized. The admission steam is expanded through nozzles which reduce the pressure from that at the stop valve, whether superheated or not, down to atmospheric pressure, after which the velocity generated in the steam is utilized in the impulse disc, which is fitted with two rows of blading—there being also one row of fixed blading. This disc is steam balanced, the steam pressures on both sides of the disc being equal. The steam admitted to the reaction section of the turbine is practically at atmospheric pressure, and at a temperature of about 212° Fahr., so that neither the turbine casing nor the rotor is exposed to high temperatures, thus eliminating one of the chief turbine troubles. The steam after leaving the impulse disc at atmospheric pressure and temperature, but having the velocity extracted, passes on to the low-pressure reaction

blading. The distance between bearings in a turbine of this type is considerably reduced. The impulse wheel is steam balanced, as has been said; the low-pressure blading being balanced by a piston at the exhaust end, so that the exhaust end gland has atmospheric pressure on both sides, and eliminates the tendency of steam to leak outwards or air to leak inwards.

The following Table, No. LVIII., will be found useful for estiting purposes, and gives the approximate costs of turbo-generators together with their complete equipment of condensing plant. The prices are over considerable ranges, because they will vary with the type of condensing plant used, and will also vary, of course, with the conditions of contract, and price of materials, at the time of tendering.

TABLE LVIII.

APPROXIMATE COST PER K.W. OF RATED OUTPUT OF STEAM TURBO-GENERATORS COMPLETE WITH CONDENSERS AND PUMPS.

A. C. Generators.

Rated output.	High pressure.	Low pressure.	Mixed pressure.	Reducing turbines.
K.W.	£	£	£	£
200 to 500	8 to 4	7·5 to 3·7	8·5 to 5	8·5 to 5
500 ,, 1,000	4 ,, 3	3·7 ,, 2·7	5 ,, 3·4	5 ,, 3·4
1000 ,, 1,500	3 ,, 2·5	2·7 ,, 2·3	3·4 ,, 3	3·4 ,, 3
1500 ,, 2,000	4 ,, 2·7	3·7 ,, 2·4	5 ,, 3·7	5 ,, 3·7
2000 ,, 4,000	2·7 ,, 2·2	2·5 ,, 2·0	3 ,, 2·5	3 ,, 2·5
4000 ,, 8,000	2·7 ,, 2	2·6 ,, 1·9	2·9 ,, 2·2	—
8000 ,, 10,000	2 ,, 1·9	1·9 ,, 1·8	2·2 ,, 2·1	—
D. C. Generators.				
200 ,, 500	8·8 ,, 4·3	8·2 ,, 4·1	9·4 ,, 5·5	9·4 ,, 5·5
500 ,, 1,000	4·4 ,, 3·3	4·1 ,, 3·0	5·5 ,, 3·6	5·5 ,, 3·8
1000 ,, 1,500	4·5	4·2	4·6	4·7

Mixed Pressure Turbines.—A mixed pressure turbine has four characteristics:—

(*a*) Operated with exhaust steam only.

(*b*) Operated with high-pressure steam only.

(*c*) High-pressure and exhaust steam simultaneously.

(*d*) High-pressure steam non-condensing.

These changes can be effected automatically without interference with the speed.

In the Westinghouse Rateau type, which may be taken as a type of this class of turbine, Fig. 74 shows both the H.P. and L.P. steam chests contained in one casting. The valves are so linked up that if there is sufficient exhaust steam available to drive the turbine, the H.P. steam is entirely cut off. Should the exhaust steam fall below the required quantity, then the governor automatically opens the H.P. valve sufficiently to keep the turbine up to its load. If the exhaust steam supply fail altogether, the L.P. valve is shut, and the whole load carried on H.P. steam. This

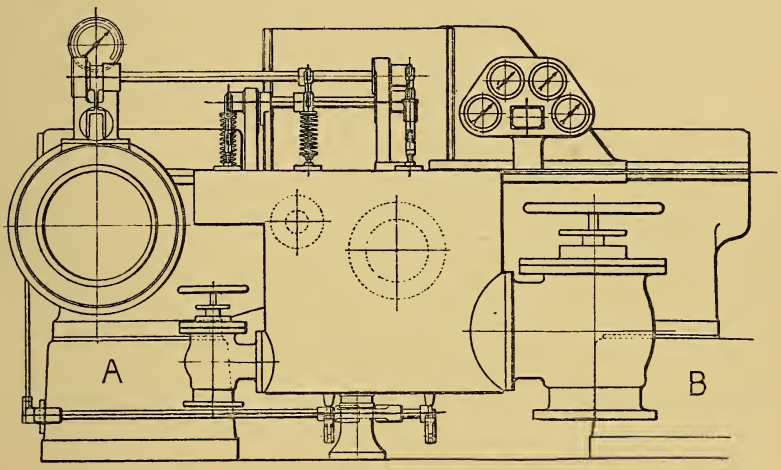


FIG. 74.

latter change prevents any back pressure being formed in the exhaust steam-pipe feeding into the turbine, so that no condensed steam can be forced back into the reciprocating engines providing this exhaust steam supply.

Fig. 75 shows a longitudinal section through a mixed pressure turbine of this type. These are especially useful where power is required for an electric power house auxiliary in works employing engines working intermittently, such as reversing rolling mills, steam winders or blowing engines, and offer an alternative to a simple exhaust-steam type with regenerator as described hereinafter.

Fig. 76 gives the H. and L.P. steam consumption on a 700-K.W, Rateau mixed-pressure turbine running at a speed of 2500 R.P.M., the guaranteed conditions being a H.P. admission of 120 lbs. per

square inch, and a vacuum of 27¾ inches (Bar. 30 in.), and a L.P. pressure of 16 lbs. per square inch, with a vacuum of 27½ inches. The figure shows not only the guaranteed consumption, but also the official figures obtained per unit generated.

Exhaust Turbines.—As a means to economy, and as a compromise between the large capital outlay on new modern plant on the one hand, and the writing off of capital expenditure and the heavier running costs of existing reciprocating plant on the other, exhaust turbines may be installed to run in conjunction with existing engines. Low-pressure turbines are fixed and inserted between the exhaust of the engines and the condenser, whereby a greatly

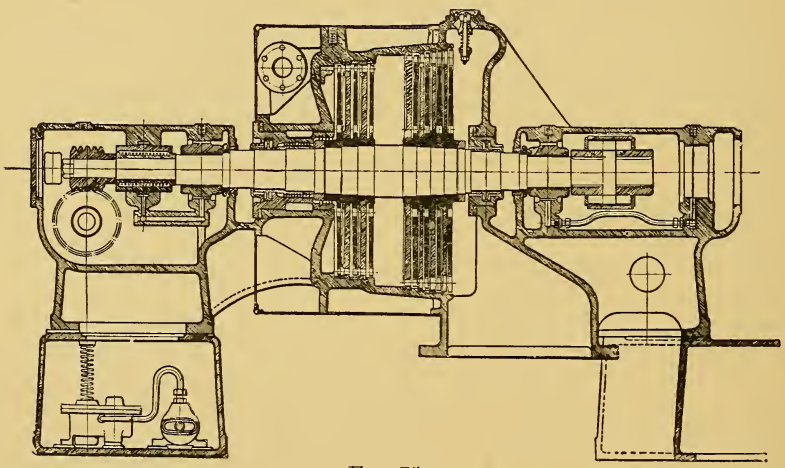


FIG. 75.

increased revenue-earning and useful plant is obtained without any additional capital outlay on boilers and buildings, and merely at the cost of the turbine unit plus some costs which may have to be incurred in improving the condensing plant. Nor is there any increase in the steam raised, the result being simply another stage or expansion added to the engine, and the thermal efficiency, taking the reciprocating engine and the turbine as one unit, being raised considerably.

The capital cost per K.W. is largely reduced, *i.e.* the revenue-earning plant is increased with only a small increment of total cost, and the running cost of fuel is enormously reduced. There-

fore the commercial efficiency of the plant is very greatly increased through the influence of both of these factors.

Fig. 77 shows a combination diagram for two 750-K.W. Belliss and Morcom reciprocating engines, and one 800–1000 K.W. exhaust turbine. The steam pressure is 180 lbs. per square inch

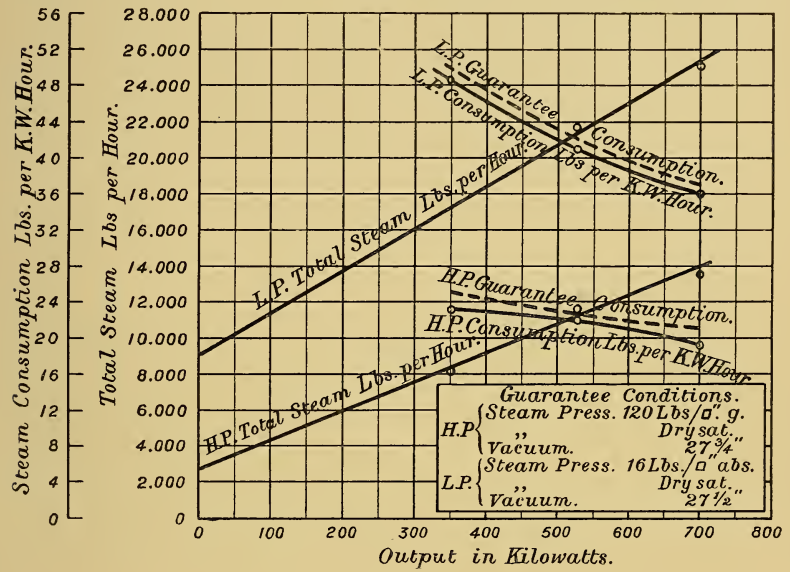

Steam Consumption Lbs. per K.W. Hour.
Total Steam Lbs per Hour.
Output in Kilowatts.
L.P. Guarantee Consumption.
L.P. Consumption Lbs per K.W. Hour.
L.P. Total Steam Lbs. per Hour.
H.P. Guarantee Consumption.
H.P. Consumption Lbs. per K.W. Hour.
H.P. Total Steam Lbs. per Hour.
Guarantee Conditions.
H.P. Steam Press. 120 Lbs/□". g.
" Dry sat.
Vacuum. 27¾"
L.P. Steam Press. 16 Lbs./□" abs.
" Dry sat.
Vacuum. 27½

FIG. 76.

at a temperature of 500° Fahr., and the curves show the resultant pounds of steam per K.W. hour for three values of the vacuum. The pressure between the engines and the turbine is 15 lbs. absolute, and the back pressure 2 lbs., 1½ lbs., or 1 lb., equivalent to a 26-, 27-, or 28-inch vacuum respectively (bar. at 30 inches). Table No. LIX. gives the steam consumption at full load.

TABLE LIX.

	Engines.	Turbine.		Combination.			
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Back pressure (lbs. absolute)	—	2	1½	1	2	1½	1
Consumption per K.W. hour	23·8	45·2	39·8	35·2	15·6	14·9	14·2
Total steam per hour	17,850	—	35,700	—	—	35,700	—
Kilowatts output	1,500	790	895	1014	2290	2,395	2514

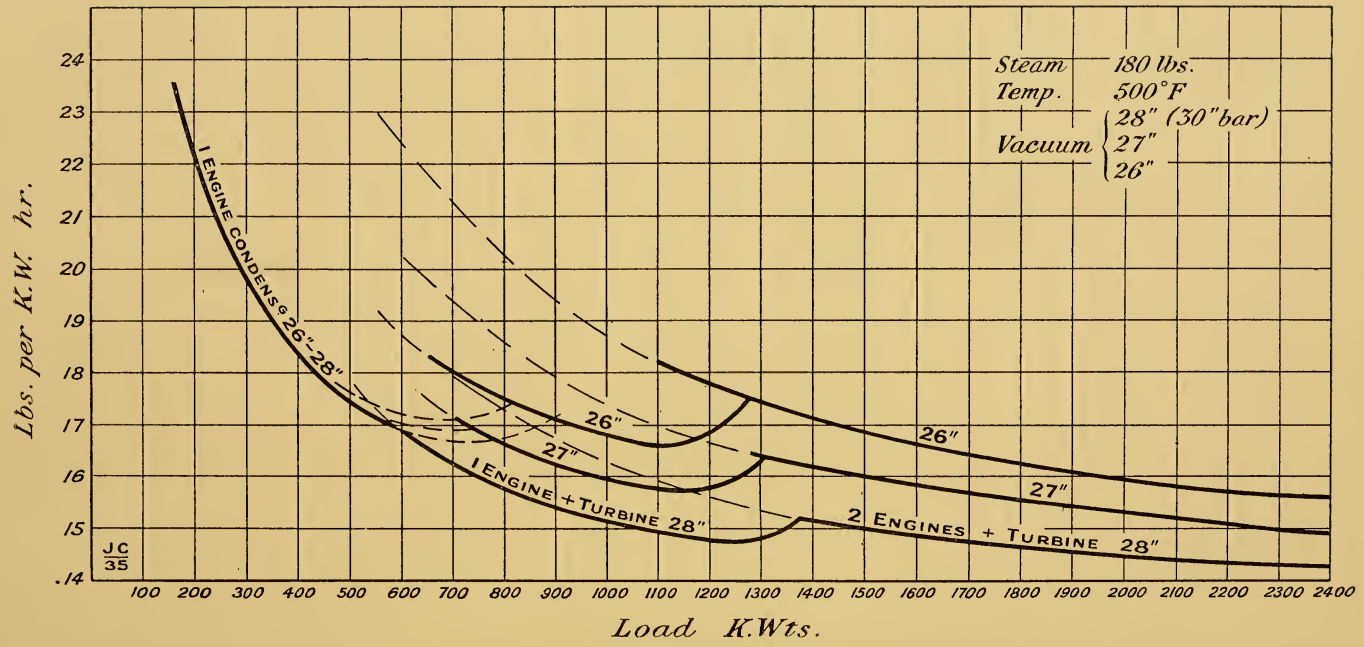

Steam 180 lbs.
Temp. 500°F
Vacuum 28" (30" bar)
27"
26"
1 Engine Condensg 26"-28"
26"
27"
1 Engine + Turbine 28"
26"
27"
2 Engines + Turbine 28"
JC 35
Lbs. per K.W. hr.
24
23
22
21
20
19
18
17
16
15
.14
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400
Load K.Wts.

Fig. 77.

Fig. 78 gives the increase in output and reduction in steam consumption per resultant K.W. hour for an engine working at 160 lbs. saturated steam and with the turbine exhausting into a 26-inch vacuum.

It will be seen that the addition of the turbine increases the total output by 52 per cent., or, in other words, the reciprocating engine contributes 72 per cent., and the exhaust turbine 38 per cent. of the total output; while the steam consumption per unit generated is reduced at full load by 18 per cent., as will be seen from Table LX. below.

In a very able paper read by Mr. W. N. Bailey before the Manchester Association of Engineers, Table No. LX. was given, from which Fig. No. 78 was prepared.

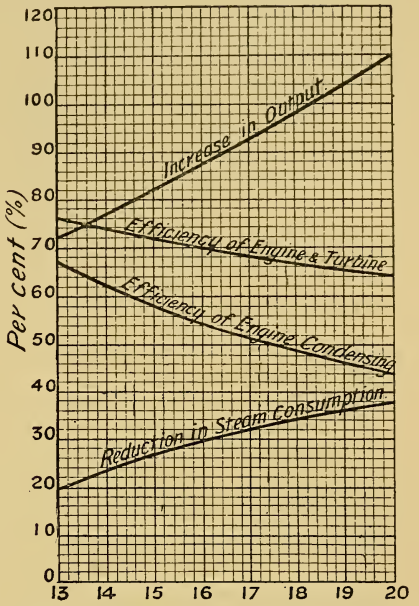


Fig. 78.

TABLE LX.

Table from which Curves in Fig. 76 are derived. 1000 I.H.P. Triple Expansion Engine and Exhaust Pressure range from 175 lbs. to 15 lbs. for Engine, from 15 lbs. to 1 lb. for Turbine.

(*Absolute.*)

A	B	C	D	E	F	H	J	K	L	M
13	67·0	80·0	17·8	10·0	1721	10·35	20·0	76·0	721	72·1
14	62·3	75·3	18·8	9·0	1770	10·64	24·0	73·7	770	77·0
15	58·2	71·2	20·0	8·4	1822	11·0	26·6	71·4	822	88·2
16	54·6	67·6	21·0	7·5	1874	11·2	30·0	70·0	874	87·4
17	51·4	64·4	22·1	7·0	1923	11·5	32·3	68·3	923	92·3
18	48·5	61·5	23·1	6·5	1971	11·73	34·7	66·8	971	97·1
19	46·0	59·0	25·0	6·1	2955	12·18	36 0	64·5	1055	105·5
20	43·7	56·7	26·0	5·7	2100	12·4	38·0	63·3	1100	110·1

A = Steam consumption of engine per I.H.P.
B = Efficiency of engine, condensing.
C = ,, ,, non-condensing (assumed).
D = Steam consumption, non-condensing.
E = Per cent. moisture.
F = Total I.H.P. output of engine and turbine.
H = Steam consumption of engine and turbine.
J = Per cent. reduction in steam consumption.
K = Efficiency of engine and turbine.
L = Equivalent I.H.P. from turbine $= \frac{\text{K.W.} \times 1{\cdot}34}{0{\cdot}92 \times 0{\cdot}9}$ and $\frac{\text{I.H.P.}}{\text{B.H.P.}} = 0{\cdot}9$.
M = Per cent. increase in output due to turbine.

Designers are very seriously asked to consider such a combination where they are dealing with extensions of existing plant. It will often be found the best compromise to improve the economy and increase the output of an existing power house by the addition of exhaust turbines, rather than building a modern power house and adopting all the latest appliances, or continuing to run an uneconomical station. A function of the engineer is to prevent waste, and to get the best out of the materials he may have ready to hand. The exhaust turbine in many cases will be found of great utility. They would not, of course, be used in any power house of modern design, since the designer would obviously proceed to the greatest economy at once by the adoption of high-pressure turbines.

There are many existing installations, such as atmospheric exhausting electrical power houses, and reversible or non-reversible mill engines where, owing to the low ratio of compounding of the cylinders or the high steam consumption, considerable economy can be gained by fixing exhaust turbines in series between the reciprocating plants and an added condensing plant. Greater economy can be obtained by these means than by the addition of a condensing plant alone. Not only is there a greater heat economy, but the commercial economy is greater, after making due allowance for the greater capital cost of the added turbine. At the Poensgen Steelworks, Dusseldorf, several engines were connected to a common condenser plant with a resultant economy of 15 per cent. By the addition of a regenerator-turbine system this economy was raised to 40 per cent.

A reference to Fig. 79 will show that the heat energy in the

shaded diagram between the admission pressure of 140 lbs. and atmospheric line is practically equal to the diagram between the atmospheric line and the practical vacuum which may be obtained in modern condensing plants without undue cost in running the condenser auxiliaries.

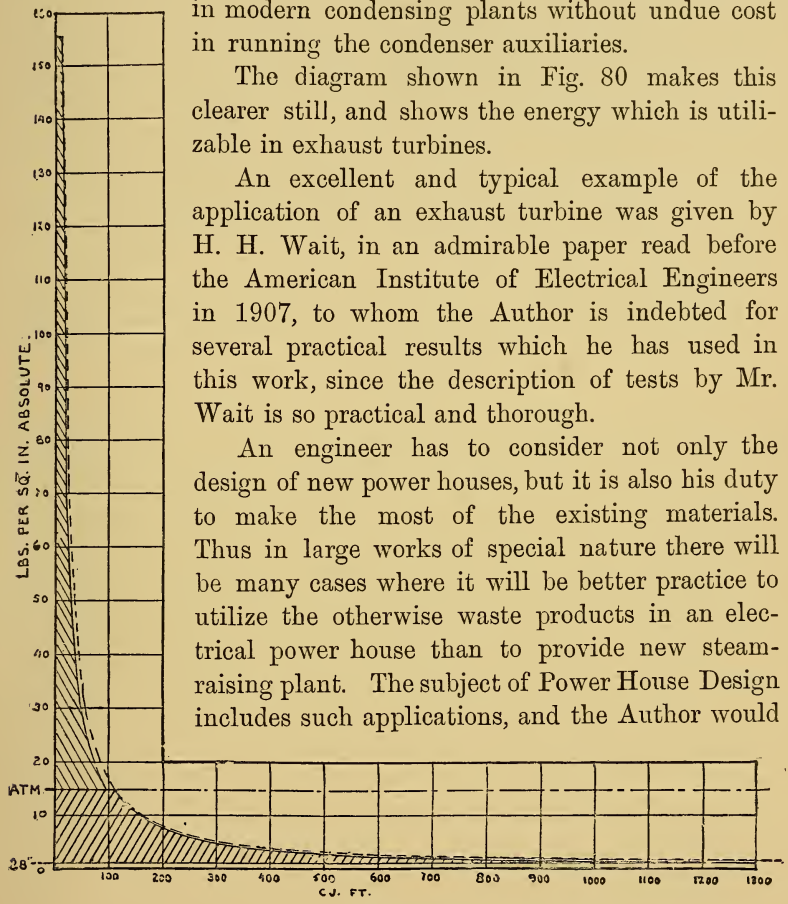


Fig. 79.

The diagram shown in Fig. 80 makes this clearer still, and shows the energy which is utilizable in exhaust turbines.

An excellent and typical example of the application of an exhaust turbine was given by H. H. Wait, in an admirable paper read before the American Institute of Electrical Engineers in 1907, to whom the Author is indebted for several practical results which he has used in this work, since the description of tests by Mr. Wait is so practical and thorough.

An engineer has to consider not only the design of new power houses, but it is also his duty to make the most of the existing materials. Thus in large works of special nature there will be many cases where it will be better practice to utilize the otherwise waste products in an electrical power house than to provide new steam-raising plant. The subject of Power House Design includes such applications, and the Author would be failing in duty and in thoroughness not to make a full reference to such applications. The plant described by Wait was installed at the Wisconsin Steel Company's Works at South Chicago, the primary engine being a 42″ × 60″ double cylinder reversible rolling mill, indicating 1010 maximum H.P., and averaging 820 H.P. per hour, thus being practically idle for 20 per cent. of the rolling,

with several stops lasting variously from a few seconds to several minutes.

The exhaust steam first passes to a receiver which equalizes

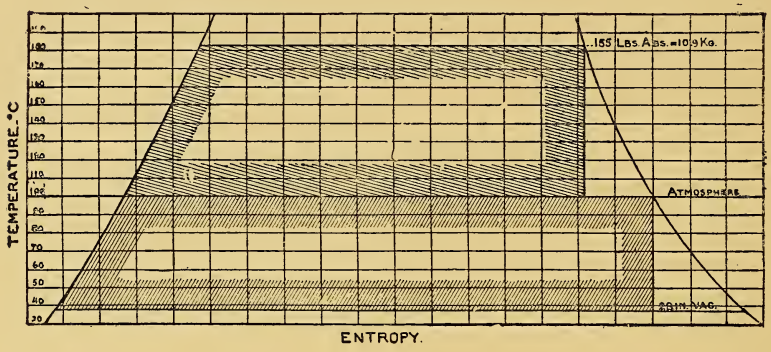


FIG. 80.

the puffs from the exhaust—which are at high pressure, since live steam is taken practically throughout the stroke—thence into a regenerator from which the turbine is supplied, and so to a condenser.

The regenerator is of a special design, as shown in Fig. 81, and so constructed that the turbine is supplied with steam at practically atmospheric pressure. It is done thus: the steam is delivered to a number of pipes immersed in the water contained in the regenerator. These pipes are perforated, so that the steam is sprayed through the mass of water. Some of the steam is thus condensed and gives up its heat to the water. The steam entering at about atmospheric pressure has, of course, a temperature of about 212° Fahr., and tends to raise the water to that temperature. When the primary engine stops and the exhaust supply ceases, there is a large volume of water at or about 212° Fahr. A steady load on the exhaust turbo-generator thus drawing steam from the regenerator, reduces the pressure in it, so that saturated steam is given off by the water then below atmospheric pressure. The primary engine again starts, and a further supply of exhaust steam comes over to the regenerator, again raising the water temperature. The regenerator is, in fact, a heat accumulator. Should the primary engine be stopped too long and beyond the storage capability of

the regenerator, then live steam is admitted through a reducing

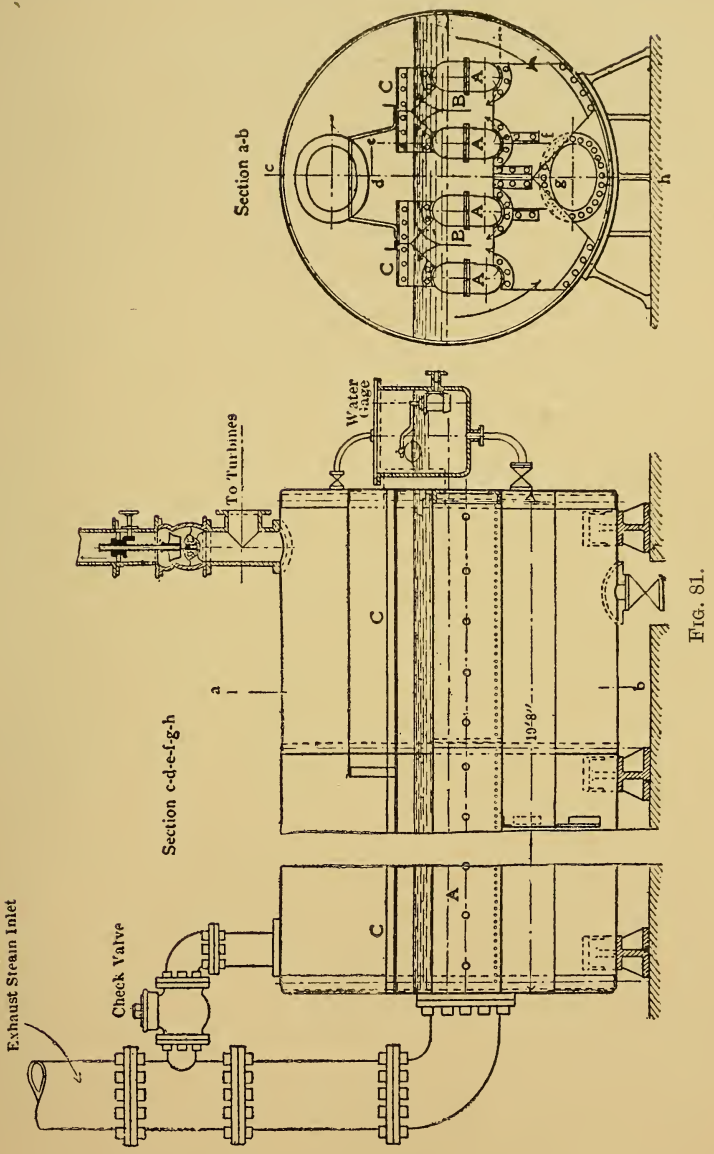


FIG. 81.

valve to make up the deficiency. On the other hand, should the

load on the turbine be too small for the time being to use up all the exhaust steam from the primary engine, then an atmospheric valve is operated and this excess steam escapes.

Any excess of water accumulating in the regenerator is drained off by a special trap.

In this example the turbine drives two dynamos, each of 300-K.W. output, and the results of four tests were as follows:—

TABLE LXI.

	I.	II.	III.	IV.
Average barometer	29·6	29·6	29·2	29·2
,, vacuum at turbine . .	25·3	26·6	26·9	26·4
,, kilowatts output . . .	266	366	489	591
,, steam per K.W. hour . .	73·3	55·2	45·2	49·5

In this case the addition of condensing plant only would have reduced the steam consumption of the reversing mills from 64 lbs. per average H.P. per hour to 38 lbs., according to the very best published results from other similar plants. By the addition of the turbine the total pounds of steam averaged over both the primary mill engine and the turbine were only 22·1, after allowing for the further condenser auxiliaries.

Figs. 82 and 82A show the general arrangement of the Rateau regenerator turbine equipment, and Fig. 83 a sectional elevation of a Westinghouse Rateau exhaust turbine.

There are many places where this supplementary power-house equipment can be utilized with great economy, not only in steel rolling mills and blast furnace blowing engines, and in some of the older reciprocating engine electrical power houses, but also in textile mills, collieries, and mines, paper mills, and other large factories. The turbo-generators can be utilized, not only for the lighting of the works and for crane driving, but also to supply motors to drive the numerous auxiliary machines required in such works.

The steam velocities in low-pressure turbines can be reduced to a low value by subdivision of the expansions into many stages. This reduces the attrition on the edges of the blades or buckets,

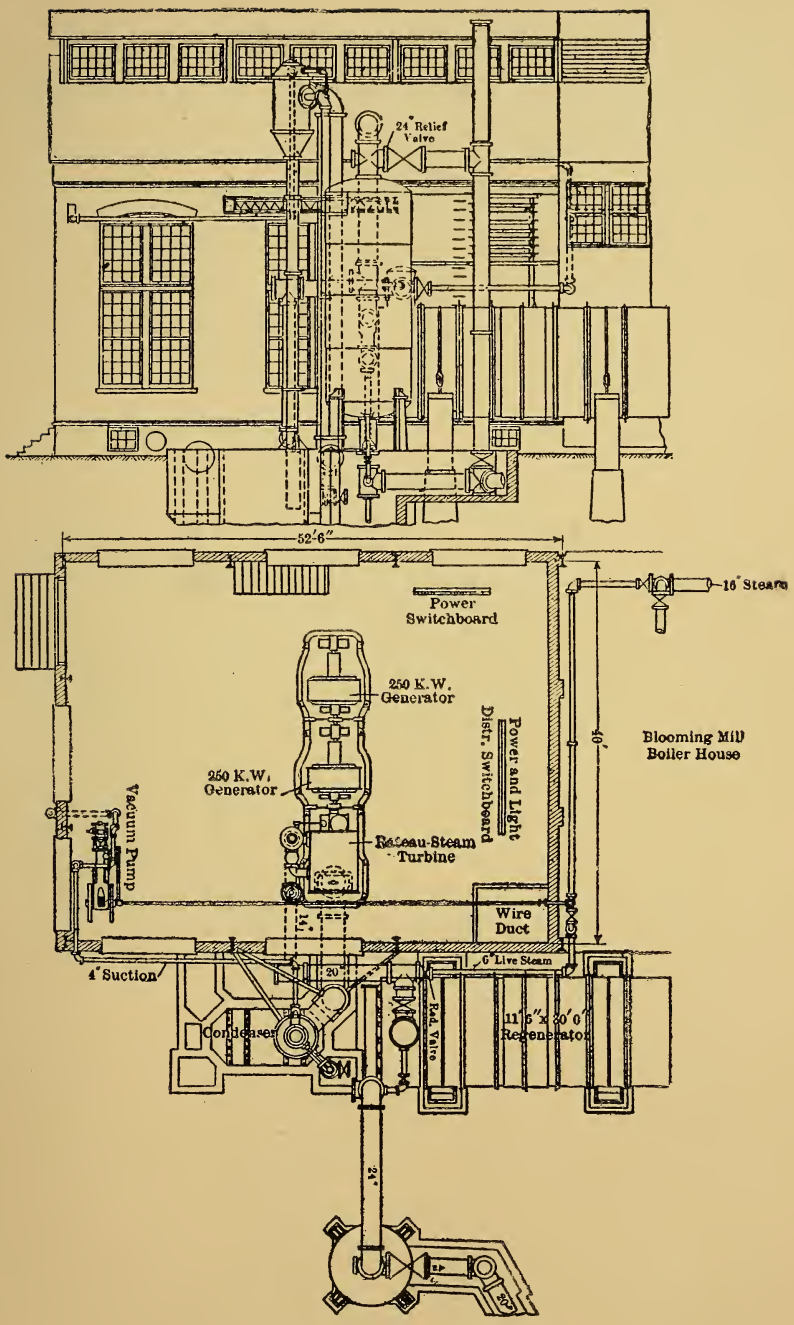

24" Relief Valve
52'6"
Power Switchboard
16" Steam
250 K.W. Generator
Power and Light Distr. Switchboard
Blooming Mill Boiler House
250 K.W. Generator
Vacuum Pump
Rateau-Steam Turbine
Wire Duct
4" Suction
6" Live Steam
Condenser
Red. Valve
11'6" x 20'0" Regenerator

FIG. 82.

and a case is authenticated where, after five years' almost continuous use, the blades still showed the tool marks. This is a

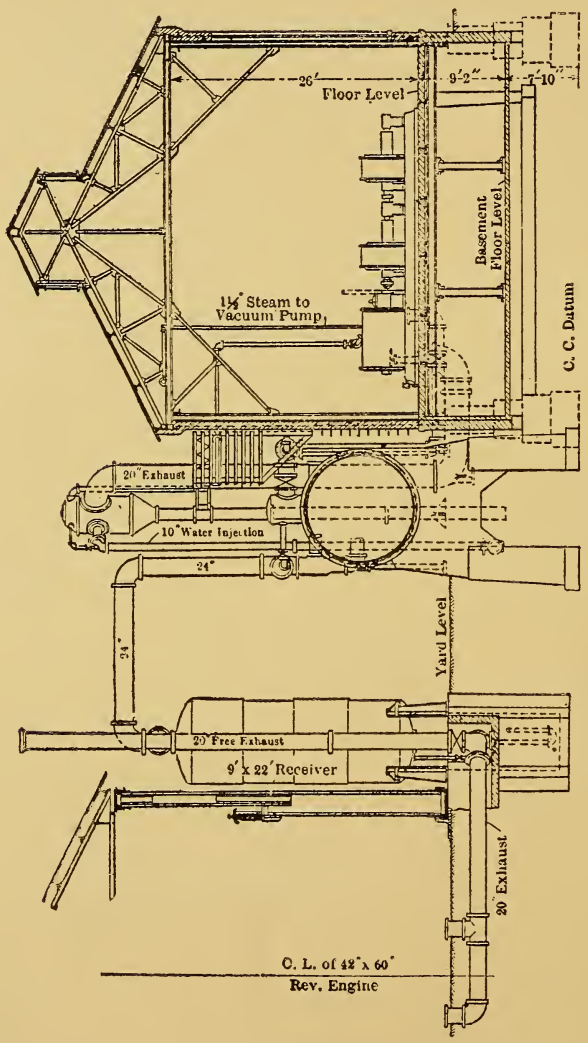


FIG. 82A.

very important item in low-pressure turbines when the steam is saturated or even surcharged with moisture.

Design of Turbine Lay-out.—In laying out turbine installations,

great care must be exercised in seeing that the steam-pipe system

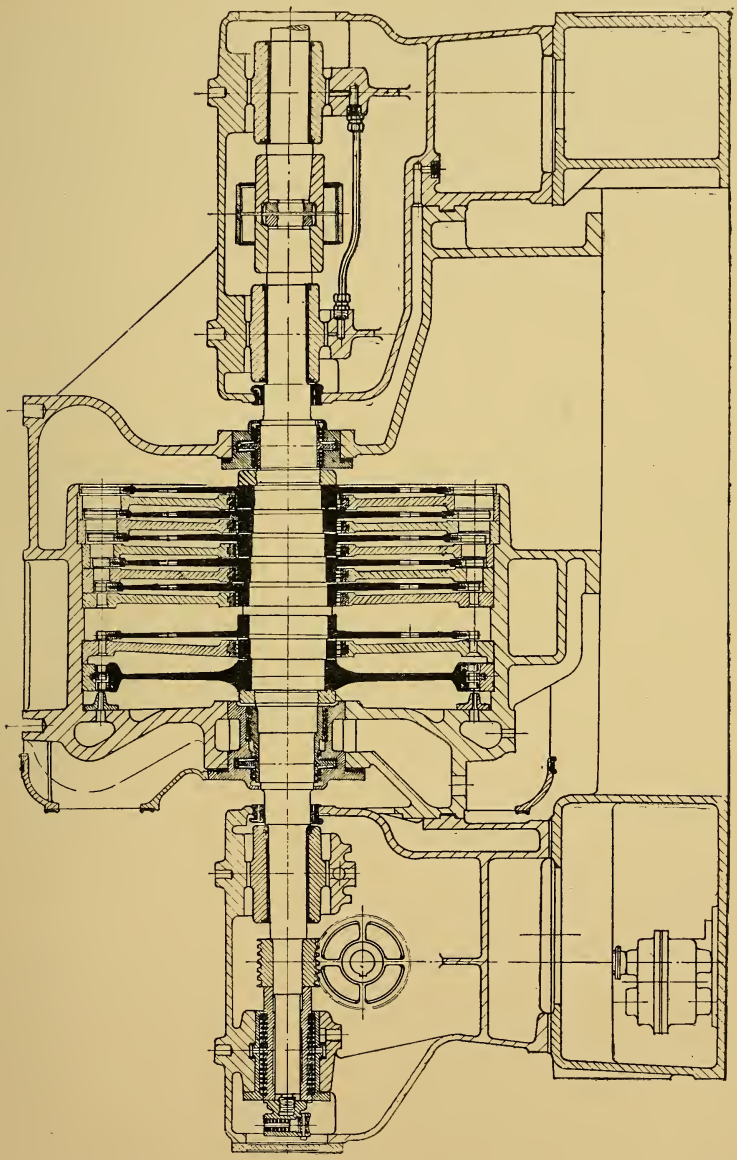


Fig. 83.

is well drained so as to prevent pockets of water being carried

into the turbine; the superheat must be carefully regulated, especially with the reaction type; the oil system must be well designed, and the turbine and its generator most carefully balanced. Plate VIII. shows a typical lay-out of a turbine, with foundations and condenser basement. A bellows, or expansion piece, is always fitted between the turbine and condenser when so placed, on account of the differences of expansion and of pressure with varying vacua. A special point in the design of a good turbine is accessibility for internal inspection and measurement of clearances without the removal of auxiliary details, such as governor levers, oil pipes, etc.

Reaction-type turbines have to be very carefully erected and lined up owing to the small clearances between fixed blades and rotor blades. On the other hand, owing to the greater difference of pressure between the (less numerous) stages of an impulse turbine, very small clearances can only be given between the shaft and the fixed diaphragms, so that unless the shaft is designed of sufficient strength, contact between these parts may arise. Means of checking the steam consumption of each turbine should be installed, such as a Lea Recorder, as this enables the engineer on duty to see at once if any strips have taken place, and the apparatus is so simple and so cheap, that it should always be fixed.

Water Loads.—Power houses should be provided with means of testing any of the sets installed on separate load apart from the main-power circuits. By doing this after periodical overhauls the economy of the plant can be maintained with the resulting economical production of energy. Water loads are usually provided for this purpose, and with high-tension plant these must be permanently and carefully arranged so as to prevent danger to both employees and to the plant itself.

The device designed by Messrs. Morcom and Walshe, consists simply of portable water-cooled inductive coils with variable cores, which are inserted in series with ordinary water tubs, or plates suspended in a pond or canal, and in which the inductance can be modified so as to bring about conditions of powerfactor in the load equivalent to those experienced under actual practical conditions.

Fig. 84 is a curve giving the temperature variation of resistance of canal water taken by Messrs. Morcom & Davies in a paper read

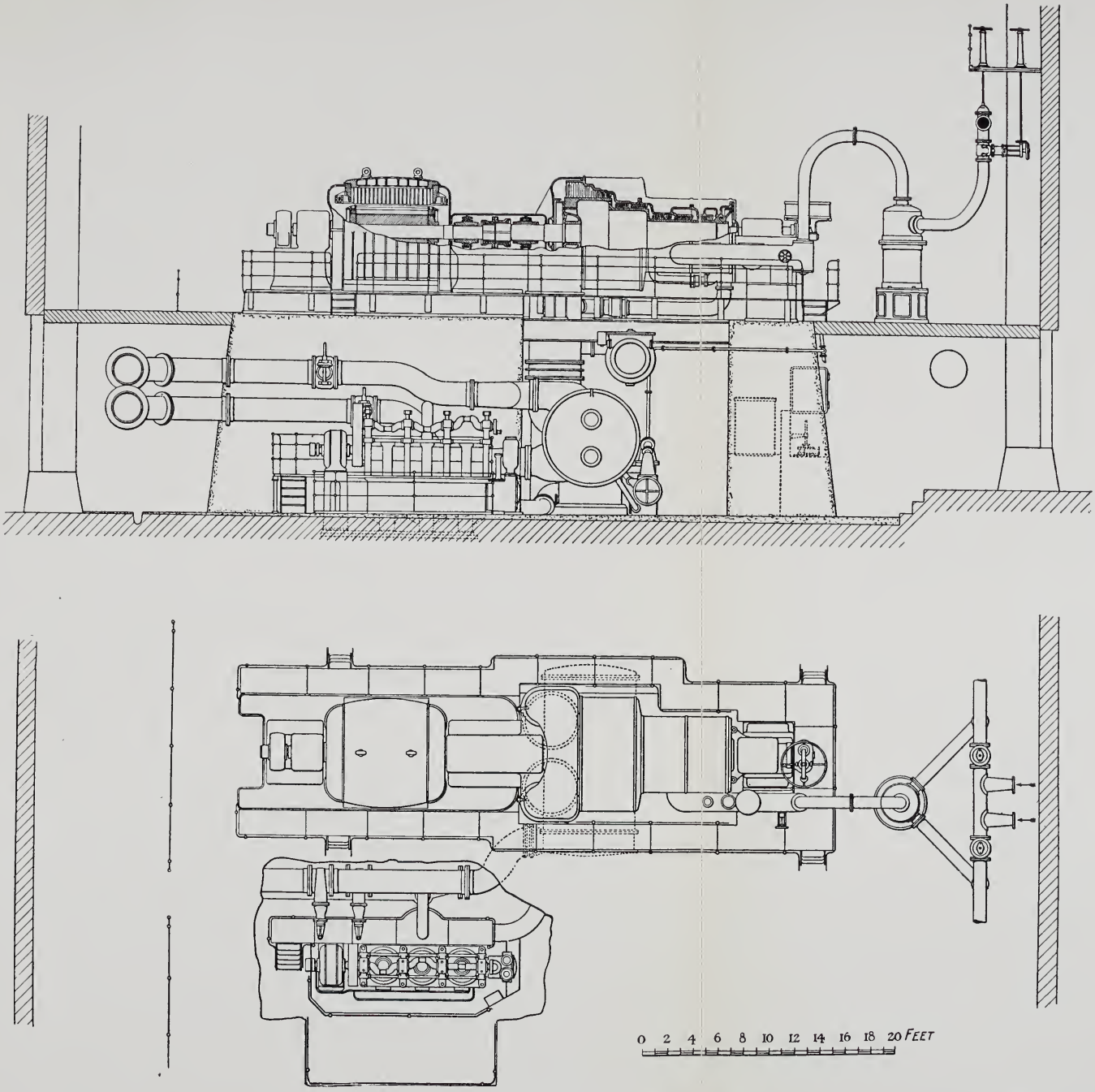


PLATE VIII.—TYPICAL LAY-OUT OF A 5000 K.W. TURBINE. [*To face page* 198.

before the Institute of Electrical Engineers in 1908, and may be taken as a basis of computation of the necessary sizes of artificial-

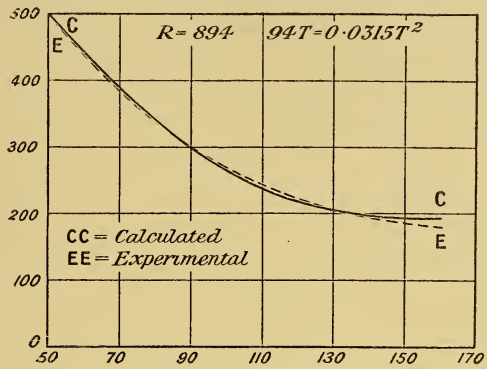


FIG. 84.

water loads. The calculated curve CC was obtained from the formula :—

$$R = R_0(1 + at + T_2)$$

This approximates very closely to the actual experimental curve EE between 50° and 160° Fahr., a range which covers practical working. Table No. LXII. sets out the particulars of certain waters tested by the authors.

TABLE LXII.

Source.	Degree of hardness.	Mineral matter in solution.	Specific resistance at 60° Fahr.	
			Per cm³.	Per ft³.
	deg.	Parts in 100,000.	ohms.	ohms.
Distilled	—	—	600,000	20,000
Condensed from as Eng.	—	About 2	66,000	2,170
Birmingham tap water	3·2	6·2	13,000	435
50% Birmingham tap, and 50% Birmingham canal	—	—	965	32
Birmingham canal	52	143	435	14
Blackburn water	—	—	17,800	560
Glasgow water	—	Particulars supplied by Mr. W. P. Digby	17,000	580
West London water	—	—	2,800	92
Rugby water	—	—	2,400	79

CHAPTER VII

CONDENSERS

THERE are some cases where an atmospheric exhaust is more economical than the adoption of condensers, as in very small power houses, or in larger power houses with poor load factors and cheap fuel. These cases are, however, rare. Even in the latter instance a part of the plant, *i.e.* the long hour plant, should as a rule be provided with condensers. The saving in steam by using condensers varies from 20 to 25 per cent. in reciprocating engines, but the whole question is, of course, a comparison of the capital cost of condensers, and the cost of running the auxiliary pumps, as against the cost of larger boilers and bigger consumption of fuel and water when exhausting to atmosphere.

There is another aspect affecting condensers. All large steam-power houses are of course run condensing; and all turbine plants are necessarily so run, for the reasons set forth in Chapter VI., when dealing with exhaust turbines. The cost of condensers for turbine plants is usually higher than with reciprocating plants, where an inch or so more or less, about 26 inches, does not greatly affect economy. With a turbine plant, however, every inch tells on the economy of steam; this is clearly shown by the steam consumption curves shown in Fig. 85, which give the effect of vacua on both high-pressure and exhaust turbines. It also affects the size of condenser in any given case and the cost of pumping the necessary amount of circulating water. Thus, every power house has its own peculiar economic problems, which a skilful designer must work out in order to get the most economical result. The items affected are:—

(*a*) Capital cost of boiler plant, including buildings.

(*b*) Capital cost of condensing plant.

(*c*) Cost of fuel.

(*d*) Annual load factor.

(*e*) Running cost of power house, which determines the cost of running condenser auxiliaries. The latter increases materially at the higher vacua.

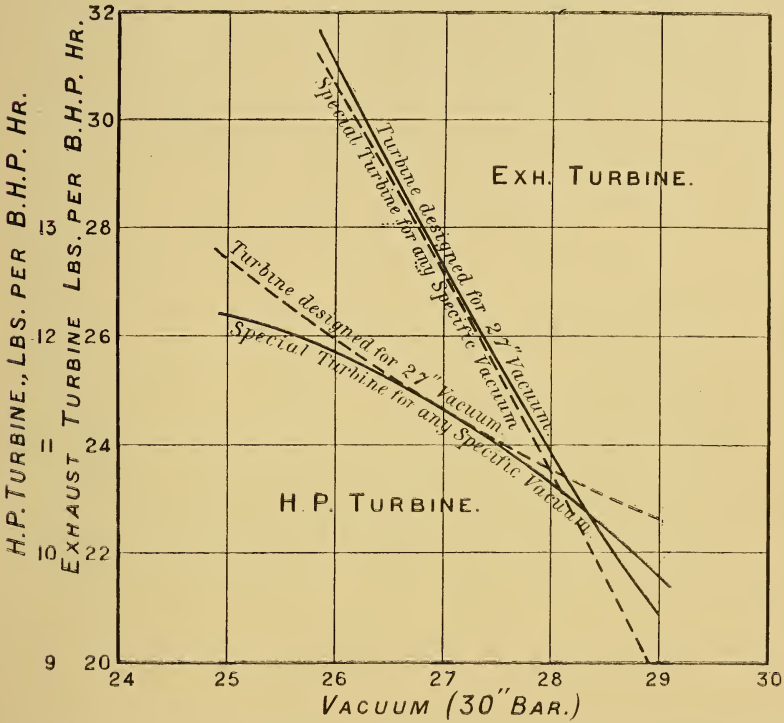


Fig. 85.—Curve showing Effect of Varying Vacua on Steam Consumption for Exhaust and H.P. Turbines.

Fig. 86 shows a series of curves, giving the most economical vacuum with an annual plant-load factor of 10 per cent. These curves are taken from a paper read by Mr. R. M. Neilson before the Institute of Electrical Engineers (England), in 1909, and have been checked by the Author.

Similarly Fig. 87 shows the curves for an annual load factor of 20 per cent., and Fig. 88 curves for 30 per cent.

In these cases the curves are based on the actual cost of boiler and condensing plant designed for a 27-inch vacuum (with barometer at 30 inches). The other points in the curves are

obtained by taking the varying steam consumptions on either side of that vacuum, varying powers for the condenser auxiliaries,

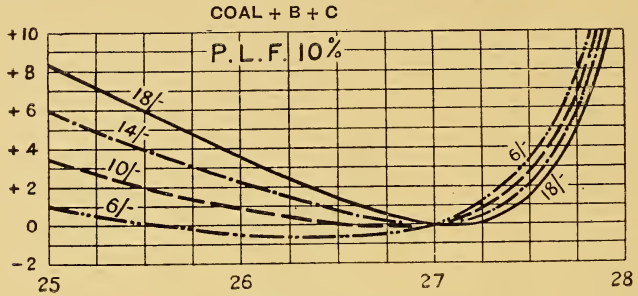


FIG. 86.

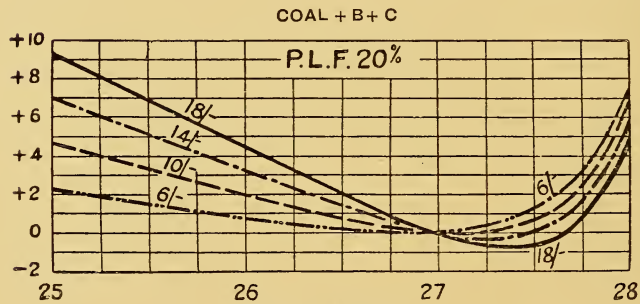


FIG. 87.

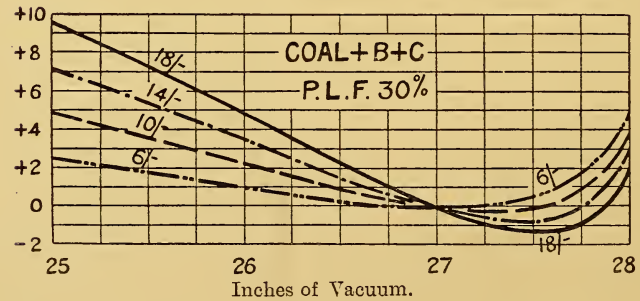


FIG. 88.

varying temperatures of hot well and corresponding increase or decrease in the boiler plant, and also in the cooling surface, affecting therefore the sizes of the condensers.

The data on which the curves are based are as follows :—

Boiler plant, £3 5*s.* per K.W. of plant installed.

Condensing plant with cooling towers, £1 4*s.* per K.W. of plant intalled.

The steam consumptions are based on known results from high-class turbines : the coal is uniformly assumed to have a value of 14,500 B.Th.U., and the evaporation per lb. of fuel from and at 212° Fahr. is taken at 9·5 lbs.

The designer can make his own corrections for any particular case.

Types of Condensers.—There are several available types of condenser, viz. the low-level jet condenser, the siphon, the barometric jet, the surface condenser, and the ejector condenser.

The efficiency of any condenser depends on the removal of the air and incondensible gases which either come over with the steam or from leakage or other sources.

Simple Jet Condensers.—The simple jet condenser has the advantage that only one pump is required, but the pump has to remove both the injection water and the condensed steam. This type has the disadvantage that the heat units in the exhaust practically are lost for boiler feed.

The injection water is obtained by means of the atmospheric pressure, and the discharge pump lifts the water to the outlet level or to the top of cooling towers, as may be necessary. The latter is usually an effective head of 25 feet neglecting pipe friction, which will vary, of course, with the relative positions of the condenser and tower. Fig. 89 shows a section through a Leblanc simple-jet condensing plant, and Fig. 90 a sectional plan. The exhaust steam enters the condenser at A, passes down and meets the cooling water injected by the Pelton wheel. The steam and injection water are thoroughly mixed, and owing to the high velocity given to the injection water by the wheel, the combined water and condensed steam are swept out against the atmospheric pressure, while creating and maintaining a high vacuum. This plant is always arranged so that it has to lift its injection water, and the Pelton wheel must, therefore, be primed ; this is done by means of a steam starting ejector shown at C in the figure. If the water supply is under pressure this ejector is, of course, unnecessary.

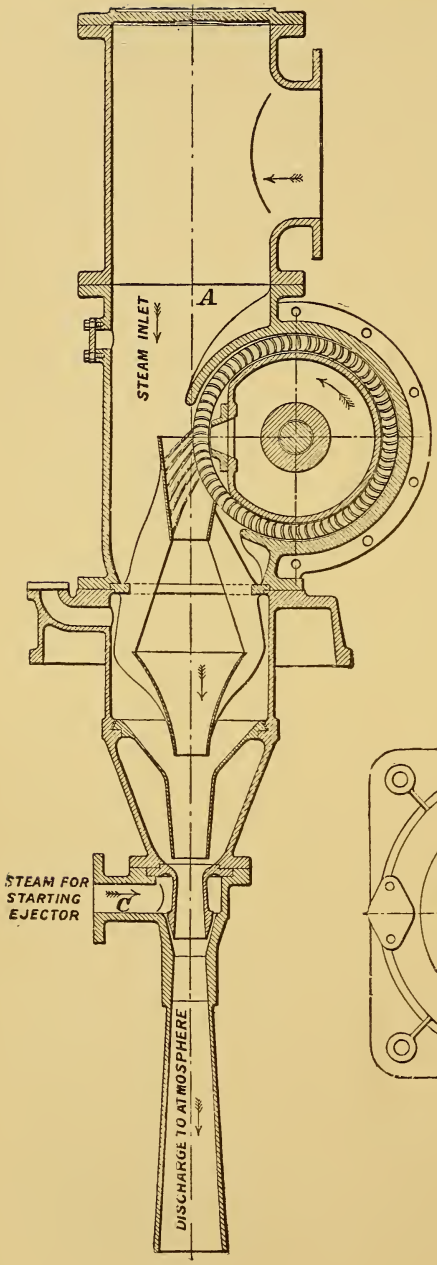


Fig. 89.

In this type the discharge from the wheel is intermittent, consisting of so many separate sheets of water shot out by the wheel blades as shown in Fig. 89. Thus the air is entrapped between successive sheets and so delivered with the discharged water. It is claimed that from six to ten volumes of air are removed to one volume of water. The limiting size is about 500 K.W.

Multiple Jet Condensers.—This type is adopted for larger units of plant. A

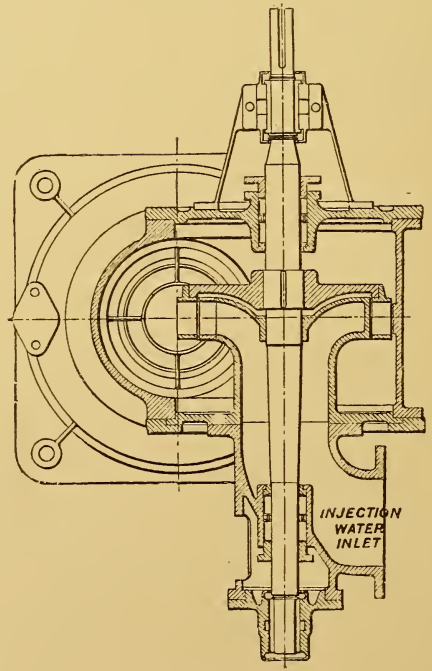


Fig. 90.

sectional arrangement is shown in Fig. 91. The steam enters at the inlet A and the injection water at B, thence passes into a distributing chamber C, and discharges into the condenser through the nozzles D. The nozzles are specially designed and fitted with vanes which split up the water jets and impart a swirling motion to them, so as to increase the contact area with the steam. The cone E is fixed so as to narrow the area through which the steam and water pass, so as to mix them intimately and produce rapid condensation. The combined steam and water fall to the bottom of the condenser, and are discharged by the wet pump F. The air and incondensible gases separate from the water, and are drawn off by the dry air pump through the section pipe G. In the type illustrated there is removed a great objection to the ordinary low-level jet condenser. In the latter water may pass back to the engine or turbine and wreck it, should the pump fail. As will be seen from Fig. 91, this danger cannot arise with this type of plant. There is an uninterrupted passage through the pump, so that if the pump should stop air rushes into the condenser through the air pump and immediately breaks the vacuum.

There is also an air valve, shown at H, controlled by a ball float, which rises with the water when it reaches a certain level, this opens the air valve admitting air to the condenser, and thus breaks the vacuum.

The following Table, No. LXIII., gives particulars of this type of condenser.

TABLE LXIII.

MULTIPLE JET CONDENSERS.

Type No.	Normal steam duty with cooling water at 60° Fahr.	Approximate power required.	Speed of pumps.	Maximum discharge lift of water-extracting pump.
	lbs. per hour.	B.H.P.	R.P.M.	
1	7,000	12	960	26 feet
2	8,800	15	960	,,
3	10,500	18·5	960	,,
4	10,500	18·5	960	,,
5	13,200	23	960	,,
6	16,000	27	960	,,
7	16,000	27	720	,,
8	19,600	33	720	,,
9	23,800	39	720	,,
10	23,800	39	720	,,

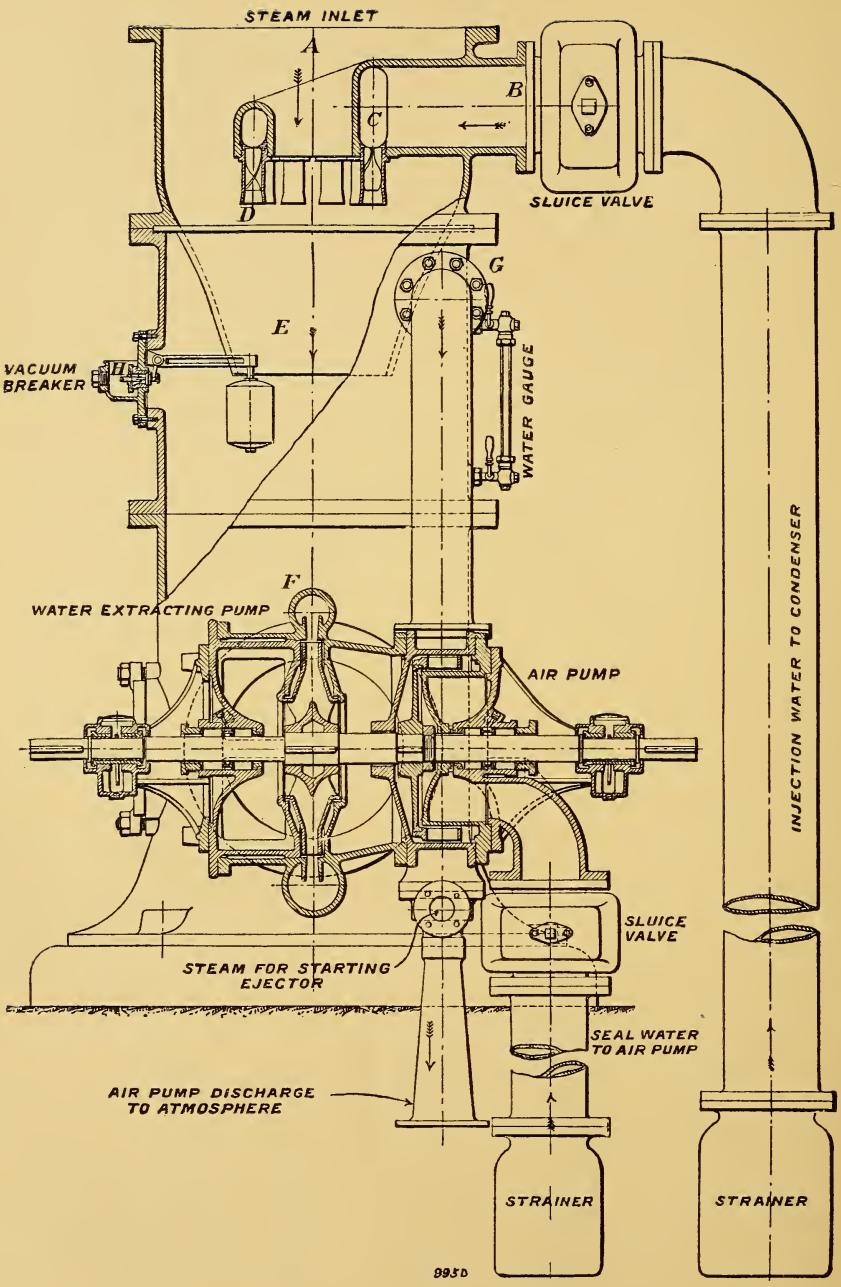

STEAM INLET
A
B
C
D
SLUICE VALVE
G
E
VACUUM BREAKER
H
WATER GAUGE
F
WATER EXTRACTING PUMP
AIR PUMP
INJECTION WATER TO CONDENSER
SLUICE VALVE
STEAM FOR STARTING EJECTOR
SEAL WATER TO AIR PUMP
AIR PUMP DISCHARGE TO ATMOSPHERE
STRAINER
STRAINER
995D

FIG. 91.

TABLE LXIII. (*contd.*).

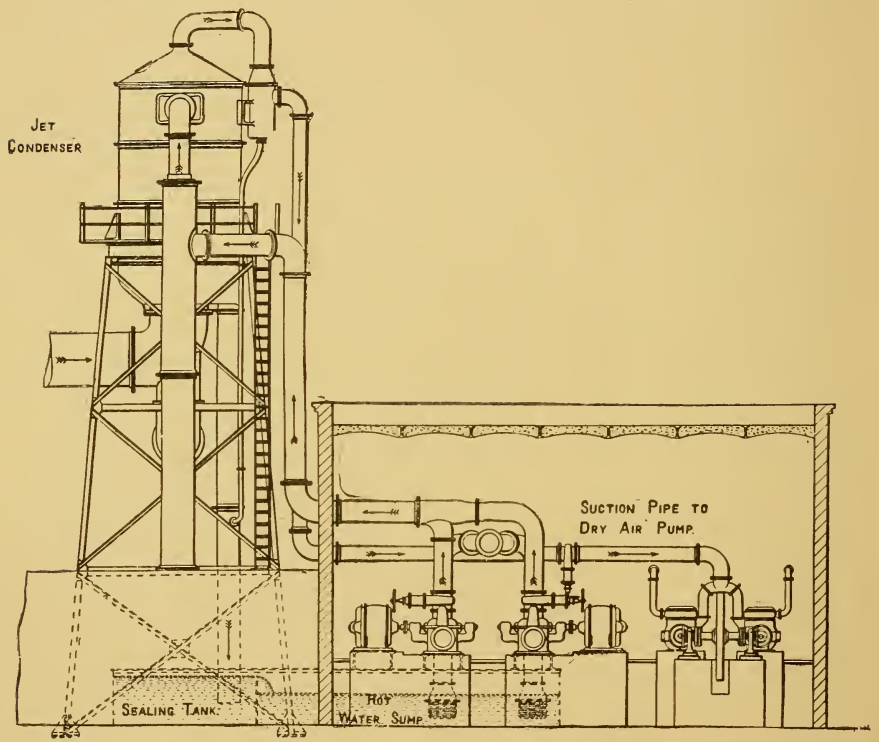
Type No.	Normal steam duty with cooling water at 60° Fahr.	Approximate power required.	Speed of pumps.	Maximum discharge lift of water-extracting pumps.
	lbs. per hour.	B.H.P.	B.P.M.	
11	30,000	47	720	26 feet
12	35,000	55	720	,,
13	35,000	55	480	,,
14	45,000	70	480	,,
15	53,000	85	480	,,
16	53,000	90	480	,,
17	65,000	100	480	,,
18	80,000	115	480	,,

Quantity of Circulating Water with Jet Condenser. — The amount of circulating water is less in jet condensers than with surface condensers, and this is especially marked at high vacua. An average difference of temperature between the exhaust steam and the discharge water may be taken at 3·5° Fahr. As an example let the vacuum maintained be 27 inches (90 per cent.), and the injection water temperature 80° Fahr. The temperature of steam at an absolute pressure of 1·5 lbs., equivalent to 27-inch vacuum, is 114° Fahr., and the equivalent total heat of saturated steam is 1116 B.Th.U. The temperature of the discharge water will thus be 114° – 3·5°, or 110·5° Fahr. Each pound of water passing through the condenser is raised from 80° to 110·5° and absorbs 30·5 B.Th.U. The amount of injection water required will thus be $\frac{1116 - 110{\cdot}5}{30{\cdot}5}$, or 33 times (nearly) the weight of steam condensed, a very much less quantity than would be possible with surface condensers. This is most important when cooling towers are required as auxiliaries, as the capital cost of the plant is reduced, and the running cost of and power absorbed by the pumps are much less.

Siphon Condensers.—The siphon type of barometric condenser is a modification of the simple jet condenser; the condenser head is fixed at a height of not less than 34 feet above the hot well, and a pipe connects this chamber with the hot well where the end is water sealed. The inside of the tube is contracted into a throat at the point where the steam and injection water mix, so that the increased velocity of the water through the

throat carries the air and vapour with it, and no air pump is needed. The barometric pressure prevents the water from backing into the engine.

Barometric Condensers.—The barometric type shown in Figs. 92 and 93 is similar to the siphon type, but has the addition of a dry air pump, which is connected to the top of the condenser head, and



Sectional Elevation
Fig. 92.

extracts air and vapour at the best point for so doing. Both these types require but small floor space, are of extremely simple construction, and are cheap in first cost. As, however, they necessarily have to be fixed away from the turbines, an addition has to be made to their cost for the very large exhaust connecting pipe between the turbine or engine and the condenser, and also an allowance for the loss of vacuum due to friction in the pipe.

The barometric types also require somewhat expensive steel framework to support the condenser head and barometric head; as the name implies, the discharge water cannot flood the exhaust range unless the injection water fed into the condenser head should exceed the amount which the vertical pipe is capable of discharging. Such a condition may arise on a high vacuum due to the sudden increase in the speed of the injection pump.

The power required to drive the pumps is approximately 75 per cent. of the power required for ordinary low-level jet con-

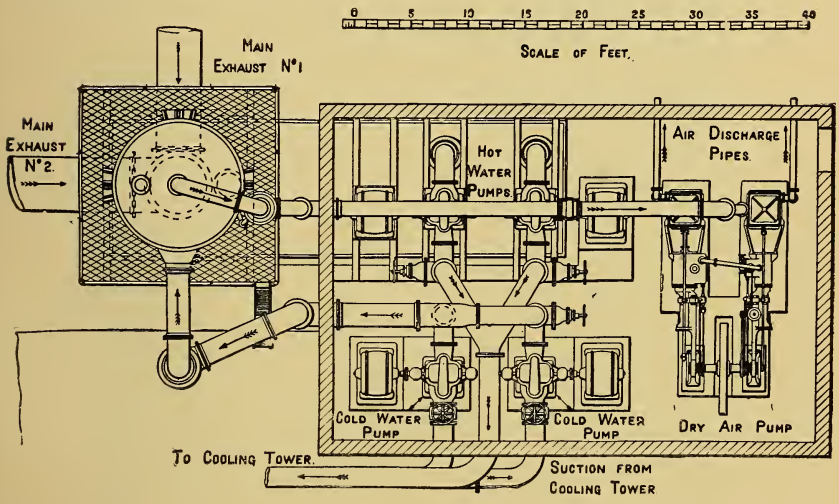


Fig. 93.

densers without external head of water, but is practically the same when working with cooling towers.

In fixing the heights of barometric condensers it must be remembered that 1 lb. below atmospheric pressure is equivalent to a water column of 27·68 inches, and therefore, for the usual atmospheric pressure of 14·7 lbs., the equivalent height is 33·9 feet.

Fig. 94 shows a barometric condenser at the Central Railway Company's power house, London. This is coupled to a 9000-K.W. steam generator. It is of the vertical counter current design with a volumetric capacity of 530 cubic feet. It is fitted with a series

of trays and baffles for distributing the cooling water. The tail pipe leading to the hot well is 15 inches in diameter. The exhaust pipe from the engine is 26 inches diameter. An exhaust oil separator is fixed immediately in front of the condenser, the oil

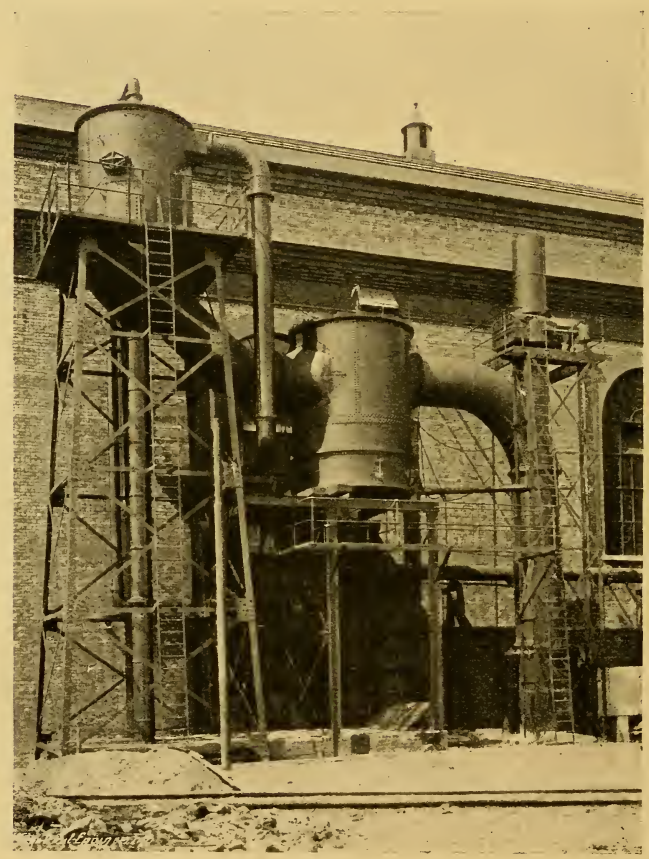


Fig. 94.

from the exhaust being withdrawn by a small steam pump which lifts the oil to a separating tank. This condenser is coupled to a brick natural draught cooling tower, having a shaft 24 feet in diameter by 115 feet in height. The tower base is 79 feet by 31 feet, and the inlet water is raised to a level of 26 feet from the foundation.

The following Table, No. LXIV., gives the cost of various sizes of barometric condensers for use with reciprocating engines, and to maintain a 26¼-inch vacuum (bar. 30 inches), complete with pumps and tanks, and also the percentage of power required to drive the auxiliaries. The table has been prepared for the Author by the courtesy of Messrs. Balcke & Co.

TABLE LXIV.

BAROMETRIC COUNTER-CURRENT JET CONDENSERS FOR RECIPROCATING ENGINES.

Vac. at engine = 26″. Vac. at condenser = 26¼″. Barometer = 30″ H.G.

Output of engine.	Approximate steam consumption.	Injection water at 60° Fahr.					Cooling tower at 80° Fahr.				
		Condenser.		Gallons per hour.	Approximate B.H.P. of air and injection pumps.	Approximate cost erected with frame-work.	Condenser.		Gallons per hour.	Approximate B.H.P. of air, injection and H.W. pumps.	Approximate cost erected with frame-work.
		Length.	Width.				Length.	Width.			
K.W.	lbs. per hr.	ft. ins.	ft. ins.			£	ft. ins.	ft. ins.			£
200	5,000	7 0	2 6	8,750	2·4	335	7 0	3 0	13,250	9·4	410
300	7,500	7 0	3 0	13,100	6·4	380	10 0	3 6	19,850	13·9	600
400	9,600	9 0	3 0	16,800	8·2	420	10 0	4 0	25,400	17·8	740
500	12,000	10 0	3 6	21,000	10·1	460	12 0	4 0	31.800	22·1	865
750	17,000	10 0	4 0	29,000	14·1	515	15 0	4 6	45,000	30·7	1020
1000	20,000	12 0	4 0	35,000	16·5	570	16 6	4 6	53,000	36·2	1140
1250	25,000	15 0	4 6	43,700	20·7	645	17 0	5 0	66,200	44·0	1290
1500	30,000	16 6	4 6	52,500	24·6	705	17 0	5 6	79,500	52·0	1420
1750	35,000	16 0	5 0	61,300	28·5	765	17 0	6 0	92,600	59·9	1565
2000	47,500	17 0	5 0	66,500	30·9	830	18 0	6 0	100,500	64·1	1735
2500	47,500	17 0	5 6	83,000	38·6	890	20 0	6 6	126,000	78·3	1900
3000	57,000	18 0	6 0	99,500	46·2	980	24 0	6 6	151,000	93·0	2095

The above figures and prices are based on standard plant working under average conditions, and must only be considered as very approximate, as each plant requires special consideration depending on circumstances.

The prices include (in the case of plant designed for water at 60° Fahr.) condenser, staging, injection and air pumps, one motor and suitable switchgear, the piping connecting pumps and condenser only, and delivery and erection on purchaser's foundations. (For plants designed for 80° water, one hot well, pump, cooler and extra motor are included.)

Similarly, Table LXV. gives a list of condensers and like information for adoption with turbines, and to maintain a 28¼-inch vacuum (bar. 30 inches).

TABLE LXV.

BAROMETRIC COUNTER-CURRENT JET CONDENSERS FOR STEAM TURBINES.

Vac. at turbine = 28". Vac. at condenser = 28¼". Barometer = 30" H.G.

Output of turbine.	Approximate steam consumption.	Injection water at 60° Fahr.					Cooling tower at 75° Fahr.				
		Condenser.		Gallons per hour.	Approximate B.H.P. of air and injection pumps.	Approximate cost erected with framework.	Condenser.		Gallons per hour.	Approximate B.H.P. of air, injection and H.W. pumps.	Approximate cost erected with framework.
		Length.	Width.				Length.	Width.			
K.W.	lbs. per hr.	ft. ins.	ft. ins.			£	ft. ins.	ft. ins.			£
200	5,000	9 0	3 0	15,900	7·3	400	10 0	4 0	29,200	19·8	810
300	7,000	10 0	3 6	22,300	10·4	435	12 0	4 6	41,000	27·1	1160
400	9,000	10 0	4 0	28,600	12·4	505	16 6	4 6	52,600	34·3	1515
500	11,000	12 0	4 0	35,000	15·5	550	17 0	5 0	64,300	41·4	1855
750	16,000	16 6	4 6	51,000	22·0	655	17 0	6 0	93,500	58·3	2195
1000	21,000	17 0	5 0	66,800	28·7	755	20 0	6 6	123,000	76·8	2565
1250	25,000	17 0	5 6	79,500	33·4	860	24 0	6 6	146,000	87·6	2965
1500	29,000	17 0	6 0	92,200	38·5	970	21 6	7 0	170,000	101·9	3390
1750	33,000	18 0	6 0	105,000	43·6	1040	24 6	7 0	193,000	114·6	3765
2000	36,000	19 0	6 0	114,500	47·9	1130	27 0	7 0	212,000	122·7	4160
2500	45,000	24 0	6 6	143,000	59·5	1325	27 0	7 6	263,000	152·6	4560
3000	54,000	21 6	7 0	172,000	71·4	1500	27 0	8 0	316,000	176·7	4950

The above figures and prices are based on standard plant working under average conditions, and must only be considered as very approximate, as each plant requires special consideration depending on circumstances.

The prices include (in case of plant designed for water at 60° Fahr.), condenser, staging, injection and air pumps, one motor and suitable switchgear, the piping connecting pumps and condenser only, and delivery and erection on purchaser's foundations. (For plants designed for 75° water, one hot well pump, cooler and extra motor are included.)

In the barometric type as in the jet, the heat units in the condensed steam are largely lost, and, moreover, when auxiliary cooling towers have to be adopted, there are additional heat units to be got rid of in the cooling tower in order to preserve the same average temperature of injection water.

Surface Condensers.—The surface-condenser type as shown in Fig. 95 is most frequently used in power houses, especially of the larger kinds. They can be readily accommodated immediately below the turbine or engine, thus ensuring the best vacuum in the low-pressure cylinder or expansion stage, and the condensed steam or hot-well discharge can be used again for boiler feed: a most important item in economy representing generally the

difference between 60° Fahr. and 110° Fahr. or 50° Fahr., and roughly 5 per cent. in the coal value.

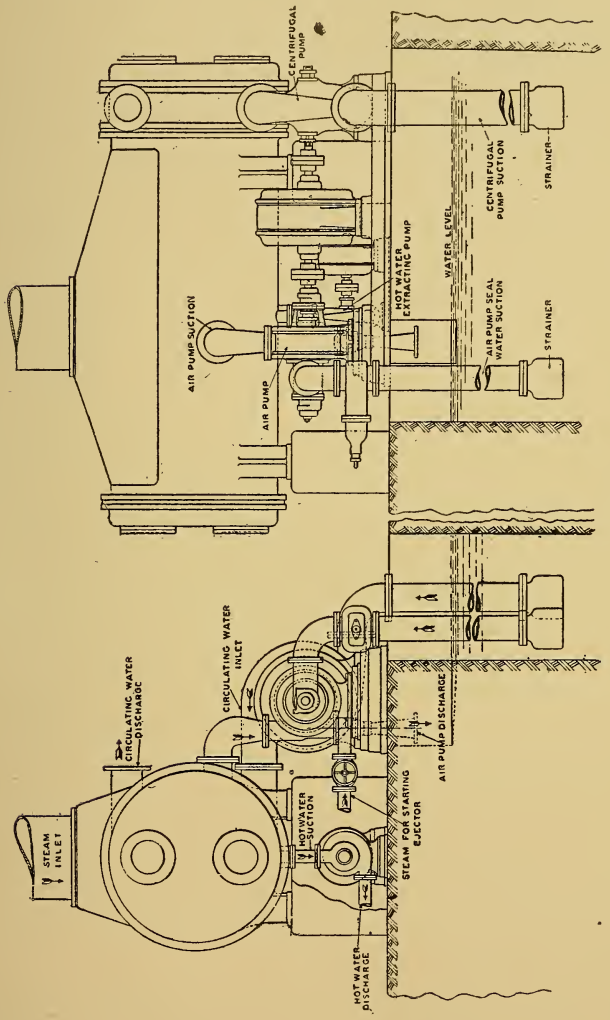


FIG. 95. (*From Manchester Association of Engineers.*)

The disadvantages of the surface condenser are :—

(*a*) Increased first cost.

(*b*) Comparative inefficiency owing to the interposition of the tubes between the steam and the circulating water. The discharged

circulating water rarely approaches nearer than some 15° Fahr. of the exhaust steam on average runs.

(*c*) The cost of cleaning and of repairs. This is practically negligible, however, when working on a turbine plant and with good circulating water.

There are several types of surface condensers, such as Morrison's Contra-flow, Le Blanc, Parsons' augmenter type, and others, which will be briefly described. The ordinary marine type usually has an allowance of 1·45 square feet of tube surface per K.W. output of steam generator if of the reciprocating type, and 2·5 square feet for turbo-generators. The tube surface has, however, to be specially fixed according to the conditions, *i.e.* whether the circulating water is drawn from a natural source, or whether it is recooled in towers, and, of course, it is also dependent on the average inlet temperature. The following Table, No. LXVI., sets out the leading practical dimensions of surface condensers, giving sizes of air and circulating pumps, power of motors, etc., for use with reciprocating engines and to maintain a 87 per cent. vacuum.

Table No. LXVII. is a list of surface condensers for use with turbines, and designed to maintain 93·33 per cent. vacuum.

There are several practical points to be considered in the condenser construction. The exhaust steam inlet should be so arranged as to give the steam access to the tubes without throttling; the tubes should be tinned carefully inside and out; the partition at the end chamber dividing the water space should be of wrought metal, and not cast; the end door should be secured by bolts at that point as well as at the flange, so as to prevent deformation, especially when the pump is delivering against a cooling tower head through the condenser. This, by the way, is not good practice, and it is better to let the water flow or be sucked through from the cooling pond by the pump so as to remove this head of water.

Parsons uses an augmenter with some of his surface-condensing plants: this consists simply of a small steam ejector which supplements the work done by the ordinary air pump, but is instrumental in maintaining a very high-percentage vacuum.

The quantity of circulating water in the surface condenser on a 27-inch vacuum with injection water at 60° Fahr. will be as

TABLE LXVI.

Counter-current Surface Condensers for Reciprocating Engines.

Vacuum at condenser = 26″. Barometer = 30″ H.G.

Output of engine.	Approximate steam consumption.	Injection water at 60° Fahr.						Cooling tower water at 80° Fahr.					
		Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of combined pumps.	Approximate cost erected with pumps.	Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of combined pumps.	Approximate cost erected with pumps.
		Length.	Diameter.					Length.	Diameter.				
K.W.	lbs. per hr.	ft. ins.	ft. ins.	sq. ft.			£	ft. ins.	ft. ins.	sq. ft.			£
200	5,000	5 0	2 6	350	13,150	3·4	370	8 0	2 6	560	17,500	8·0	695
300	7,500	7 6	2 6	530	19,700	5·0	455	8 6	3 0	840	26,200	11·7	865
400	9,600	7 0	3 0	670	25,200	6·2	505	8 6	3 6	1040	33,600	14·7	1020
500	12,600	8 6	3 0	840	31,500	7·7	560	11 0	3 6	1350	42,000	18·1	1185
750	17,000	10 0	3 6	1200	44,700	10·6	700	11 6	4 0	1900	59,500	24·8	1430
1000	20,000	11 6	3 6	1400	52,600	12·6	765	13 6	4 0	2240	70,000	28·5	1580
1250	25,000	10 6	4 0	1750	65,600	15·4	875	12 6	4 6	2800	87,500	35·0	1800
1500	30,000	12 6	4 0	2100	79,000	19·4	960	12 6	5 0	3360	105,000	43·3	2000
1750	35,000	11 0	4 6	2450	92,000	22·5	1080	14 6	5 0	3920	122,500	50·1	2260
2000	38,000	12 0	4 6	2660	100,000	24·3	1140	13 6	5 6	4250	133,000	53·7	2460
2500	47,500	12 6	5 0	3320	125,000	30·2	1365	16 6	5 6	5320	166,000	65·7	3010
3000	57,000	45 0	5 0	4000	150,000	36·1	1520	16 0	6 0	6400	199,500	78·2	3600

The above figures and prices are based on standard plant working under average conditions, and must only be considered as very approximate, as each plant requires special consideration depending on circumstances.

The prices include (in the case of plant designed for water at 60°) condenser, circulating air and extracting pumps, one motor and suitable switchgear, the piping connecting pumps and condensers only, and delivery and erection on purchaser's foundations. (For plants designed for 80° Fahr. water, the cooler is also included.)

TABLE LXVII.

Counter-current Surface Condensers for Steam Turbines.

Vacuum at condenser = 28″. Barometer = 30″ H.G.

Output of turbine.	Approximate steam consumption.	Injection water at 60° Fahr.						Cooling tower water at 75° Fahr.					
		Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of combined pumps.	Approximate cost erected with pumps.	Condenser.		Tube surface.	Gallons per hour.	Approximate B.H.P. of combined pumps.	Approximate cost erected with pumps.
		Length.	Diameter.					Length.	Diameter.				
K.W.	lbs. per hr.	ft. ins.	ft. ins.	sq. ft.			£	ft. ins.	ft. ins.	sq. ft.			£
200	5,000	8 6	2 6	600	20,500	4·4	450	8 6	3 0	850	38,500	14·9	975
300	7,000	8 6	3 0	840	28,700	6·1	555	10 0	3 6	1190	54,000	20·4	1170
400	9,000	9 0	3 6	1090	36,800	7·7	630	9 6	4 0	1530	69,400	25·5	1345
500	11,000	11 0	3 6	1330	45,100	9·1	700	9 6	4 6	1870	84,700	30·1	1505
750	16,000	11 6	4 0	1930	65,600	13·0	880	12 6	4 6	2720	123,200	40·1	1875
1000	21,000	11 6	4 6	2540	86,100	18·7	1035	13 6	5 0	3560	161,700	54·7	2275
1250	25,000	13 6	4 6	3000	102,500	21·6	1175	16 0	5 0	4250	192,500	63·8	2620
1500	29,000	13 0	5 0	3500	119,000	24·8	1280	15 6	5 6	4920	223,500	75·0	2990
1750	33,000	15 0	5 0	4000	135,200	28·3	1455	17 6	5 6	5600	254,000	85·5	3360
2000	36,000	13 6	5 6	4350	147,700	30·5	1585	15 0	6 0	6100	277,000	93·0	3740
2500	45,000	17 0	5 6	5450	184,500	37·7	1970	16 0	6 6	7650	347,000	116·5	4760
3000	54,000	16 0	6 0	6500	221,500	44·9	2320	16 0	7 0	9200	416,000	134·0	5775

The above figures and prices are based on standard plant working under average conditions, and must only be considered as very approximate, as each plant requires special consideration depending on circumstances.

The prices include (in the case of plant designed for water at 60°) condenser, circulating air and extracting pumps, one motor and suitable switchgear, the piping connecting pumps and condenser, and delivery and erection on purchaser's foundations. (For plants designed for 75° water, the cooler is also included.)

follows: the temperature of the exhaust steam is 214° Fahr., and the total heat 1116 B.Th.U. The discharged water temperature under the best conditions will be 214° − 115° or 99° Fahr., so that each pound of circulating water will take up 99 − 60 or 39 B.Th.U. The quantity of circulating water to condense 1 lb. of steam will thus be $\frac{1116 - 99}{39}$ or 26 lbs. approximately. To compare with the jet condenser example (page 207), if the circulating water were 80, the quantity would be 53·5 lbs. per lb. of steam condensed.

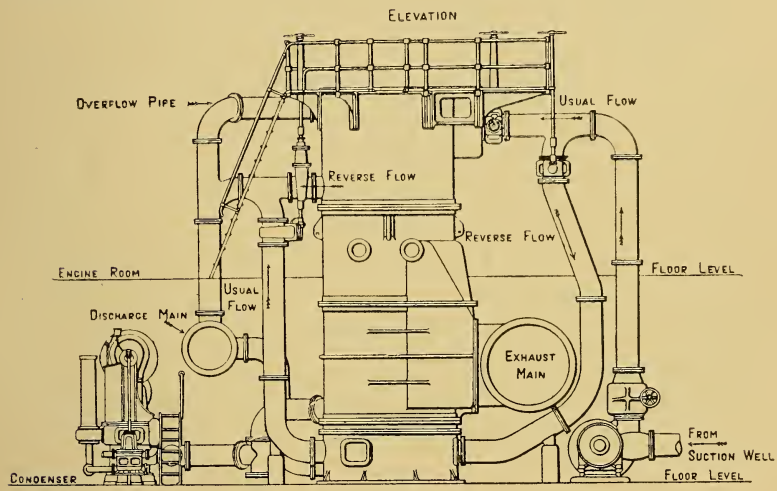


FIG. 96.

Vertical Surface Condensers for Dirty Water.—Surface condensers are made in various forms, usually horizontal with cylindrical bodies, sometimes horizontal rectangular bodies and also vertical bodies with circular sections. Figs. 96 and 97 show an elevation and plan respectively of the latter type made by the Mirrlees Watson Co., of Glasgow, for the Leeds Corporation, where the circulating water is dirty, being drawn from a neighbouring small river containing at certain seasons of the year many leaves as well as straw and other materials. The tubes are larger in diameter than usual, being $1\frac{1}{8}$ inch external, instead of the more usual $\frac{3}{4}$ inch. There are 11,000 feet of cooling surface; the water

passes only once through the full length of the condenser. The plant is designed to deal with 65,000 lbs. of steam per hour, giving

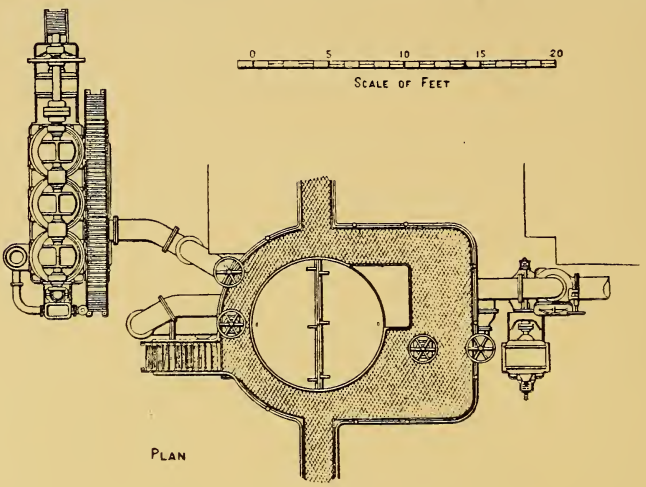


Fig. 97.

a vacuum of 28 inches (bar. 30 inches) with condensing water at a temperature of 60° Fahr.

The air pumps are three-throw Mirrlees-Edwards.

The following test was taken after running in the power house for over 12 months, as shown in Table LXVIII.:—

TABLE LXVIII.

Load on plant.	Barometer.	Vacuum.	Equivalent vacuum with bar. 30".	Circulating water. Temp. degrees Fahr.		Temp. of air-pump discharge.
				Inlet.	Outlet.	
lbs. of steam per hour.	ins.	ins.				deg. Fahr.
30,000	29·4	28·25	28·85	62	78	88
30,000	29·4	28·30	28·90	62	78	87
30,000	29·5	28·25	28·75	61	76	86
30,000	29·4	28·40	29·00	60	76	86

De-oiling Apparatus for Condensers.—With reciprocating-engine plants it is necessary to prevent the oil taken over by the exhaust steam being deposited in the condenser tubes, as this reduces

considerably the effective transmission of heat from the steam to the water. This can be to some extent reduced by interposing an exhaust separator as shown in Fig. 98, by means of which the velocity of the exhaust steam is reduced, and by a suitable set of baffles, the oil is deposited in the separator, and removed by small auxiliary pumps.

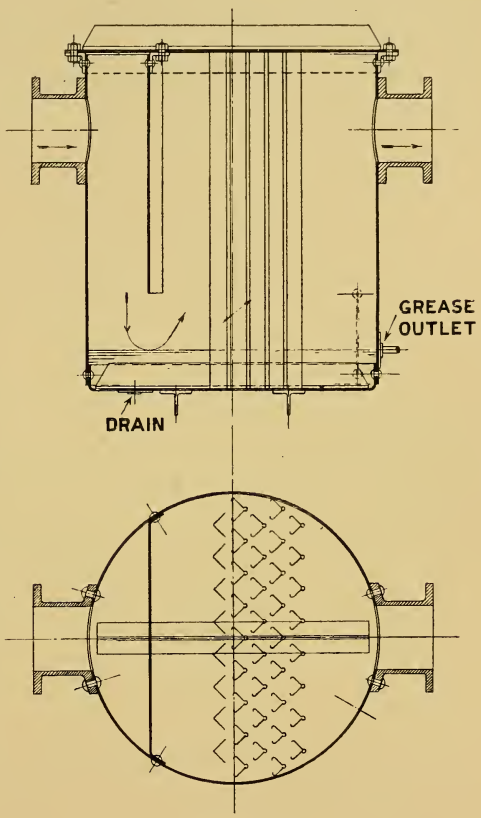


Fig. 98.

Advantages of separate Wet and Dry-air Pumps.—The old practice was to remove both the condensed steam and the air and incondensible gases by the same pump. There are two objections to this, viz. the air is not withdrawn from the condenser at the most effective point, and also the water discharged to the hot well becomes aërated, and is repumped in that condition into the boilers. It is better practice to have two separate pumps, viz. a wet pump withdrawing the condensed steam from the lowest point of the body, and a dry-air pump to remove the air and other incondensible gases from the upper portion of the condenser body. In connecting turbines to surface condensers they should either be connected through a "concertina" to take up differences of expansion, or the condenser can be bolted rigidly to the exhaust flange and mounted on springs.

Steam and Electrically-driven Air Pumps.—Some designers

prefer steam-driven, others electrically driven pumps. The former claim that a failure of the pumps and therefore of the vacuum, so seriously affects the whole plant, that, even at the expense of some economy, it is preferable to drive these from the boilers direct, rather than through the intermediary of engines, generators, and switchgear. The latter claim that the risk of failure of supply to these auxiliaries is negligible if properly provided for, and that it is more economical to adopt electrical pumps, thus saving donkey

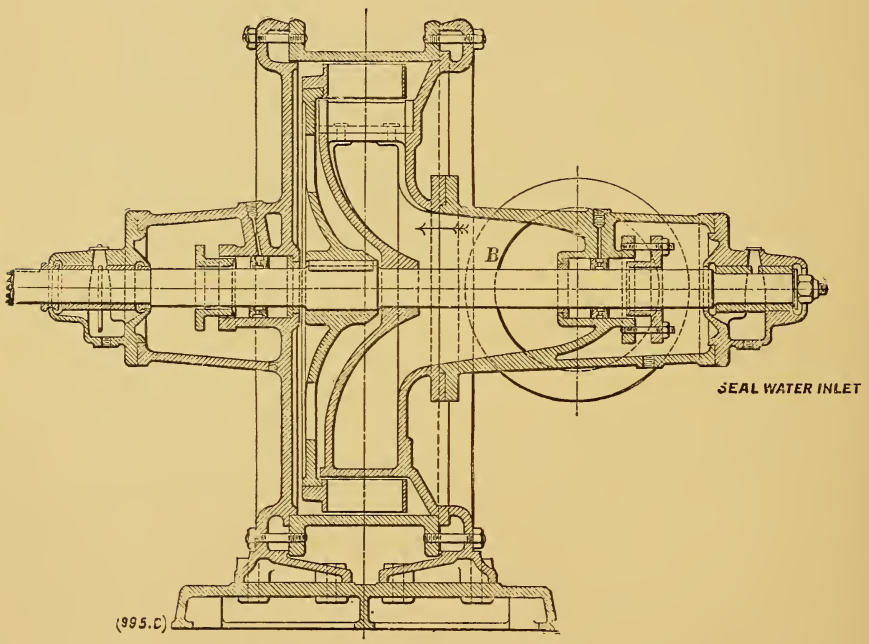


Fig. 99.

steam pipes and complication of the pipe lay-out, and also improving the plant-load factor. In steam-driven sets, the amount of steam required to drive the condenser engine if compounded is usually about 2·5 per cent. of the total steam condensed by the set; the steam consumption of the condenser engine being about 18 lbs. per I.H.P. hour. The exhaust steam from these auxiliaries should preferably be taken through exhaust feed-water heaters in series with the economisers.

Electrically driven pumps have the advantage of higher speeds and greater ease of installation and design of the power house. In turbine-driven plants the power required is some 3·5 to 4 per cent.

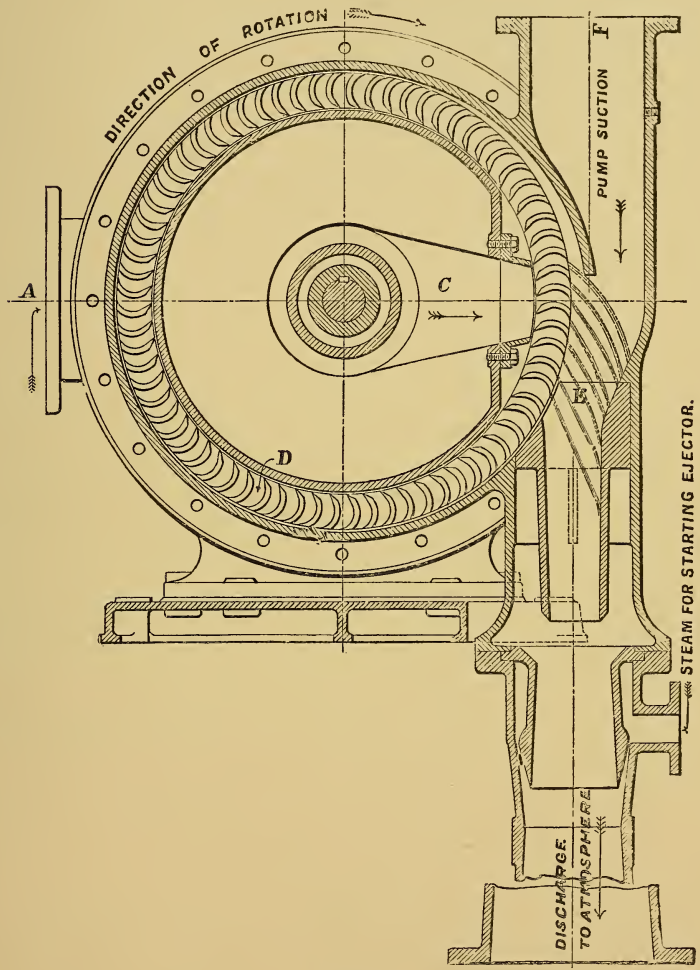


FIG. 100.

of the total rated load in the plant, and in reciprocating plants where so high a vacuum is not required, about 3 per cent. Power for power, therefore, the electrically driven auxiliaries are less economical. Taking into account, however, the radiation losses

and drainage from the extra steam pipe in the former system and the extra cost of repairs to the steam plant as compared with, say, a low-tension A.C. motor, there appears to be little to choose between the two in the point of running costs. The greater adaptability of the motor especially to circulating pumps, points to the condenser pumps being electrically driven in future power houses.

Fig. 99 shows a longitudinal section, and Fig. 100 a cross-section of a Le Blanc rotary dry-air pump. This consists primarily of a reversed Pelton turbine wheel together with an ejector. Sealing water is admitted through inlet A to the central chamber B, from which it passes through the post C. The water is then caught up by the blades D, and ejected into a discharge cone or nozzle at high velocity, and in thin sheets, which meet the sides of the nozzle and form absolutely tight-water pistons. These entrap the air and incondensible gases drawn over from the condenser through the suction inlet F, and carry them out against the atmospheric pressure. The same sealing water is used over and over again, since no appreciable rise in temperature occurs in passing through the pump, or it may be passed through the condenser as circulating water. The rotary-air pump is driven at high speed and coupled direct to a motor, or, in some cases, to a steam turbine.

There are no reciprocating parts, valves, waste-clearance spaces, or buckets, and the efficiency is high, the attention and maintenance trifling. This type of plant is particularly applicable to turbine plants, as it is able to attain a high-percentage vacuum.

In a test conducted for the Author the following figures were obtained, as shown in Table LXIX. :—

TABLE LXIX.

CONDENSER TEST (BAR. 30·1″).

Steam condensed per hour.	Vacuum on condenser.	Energy consumption of pumps.	Load on plant.	Percentage of power absorbed by pumps.
lbs.	ins.	K.W.H.	K.W.	
19,900	28·5	40·08	1052	3·8
22,900	26·75	38·70	1302	2·9
24,500	26·25	40·56	1393	2·9
15,000	25·5	39·66	824	4·8
15,780	26·0	33·60	870	3·8
(Aver.) 19,476	26·6	38·52	1088	3·6

The following Table, No. LXX., gives the particulars of three-throw Edwards air pumps for working in connection with surface condensers. The particulars apply to the conditions of maintaining a 28-inch vacuum with the barometer at 30 inches, and with the circulating water at an inlet temperature of 60° Fahr. For a vacuum of only 26 inches (barometer 30 inches) the pumps would, of course, deal with increased quantities of steam, and the pumps would run at a considerably higher speed. In the table it is assumed the pumps will not have to deliver against a head. The motors must be capable of giving the B.H.P. stated continuously, and the speed should never exceed six times that of the air pump. The weights of the motors are not included in the table.

TABLE LXX.

Amount of steam in lbs. per hour.	No. of pump barrels.	Diameter.	Stroke.	Revolutions per minute.	B.H.P.	Approx. nett weight without motor.	Approximate dimensions.		
		ins.	ins.			cwts.	ft ins.	ft. ins.	ft. ins.
7,500	3	8	8	150	3	40	5 0	7 3	1 11
10,500	3	9	9	150	4½	46	5 0	7 9	1 11
14,500	3	10	10	150	6½	56	5 9	8 3	1 11
21,000	3	12	10	150	9	75	6 2	9 0	2 4
25,000	3	12	12	150	11	78	6 9	9 0	2 4
29,000	3	14	10	150	12	96	6 11	9 9	2 6
33,000	3	14	12	145	14	100	6 11	9 9	2 6
42,000	3	16	12	140	18	107	6 11	11 0	2 10
53,000	3	18	12	140	22	116	6 11	12 0	3 0

Circulating Pumps.—Table No. LXXI. sets out the sizes of some typical circulating pumps with the H.P. required per yard of head on the pump, including the equivalent loss of head due to pipe friction and bends.

TABLE LXXI.

CIRCULATING PUMPS.

Diameter of impellor (inches) .	21	24·5	27·5	31	34·5	39·5	43
Discharge per minute (gallons)	770	1100	1760	2200	2970	3740	4510
Revolutions per minute for stated head of 24 feet . .	540	460	420	370	330	290	270
H.P. required per yard of head	1·42	1·83	2·84	3·66	4·57	5·95	7·13
Net weight (tons)	0·7	0·94	1·28	1·68	2·06	2 58	3·15
Approximate cost, electrically driven . . . . . £	63	75	88	96	119	174	203
Approximate cost, steam driven £	80	85	110	122	142	170	195

Fig. 101 is a curve by W. N. Bailey, showing the quantity of circulating water required for surface and for barometric condensers.

The following test of a 5000-K.W. turbine shows the power required by auxiliaries (Table No. LXXII.) :—

TABLE LXXII.

Turbine K.W.	2713	3410	4758
Vacuum inches	28·4	28·7	28·6
Barometer inches	29·53	29·95	29·96
Circulating pump I.H.P.	69·1	69·1	69·1
Dry air pump I.H.P.	24·3	23·2	23·8
Wet air pump E.H.P.	8·6	9·2	9·8
Step bearing pump I.H.P.	6·4	5·8	5·6
Total pump H.P.	108·4	107·3	108·3
Per cent. of turbine H.P.	4%	3·14	2·27

Reference may also be made to a previous Table, No. LIV., p. 175.

Summary on Condensers.—Simple or multiple jet condensers may be adopted with reciprocating engines, and offer a cheaper initial cost. The oil which is brought over from the engine renders it necessary to treat the water by some means to extract the oil before it can be used again in the boilers. By using jet condensers, however, though initially cheaper, and requiring less circulating water than surface condensers, the condensed steam is rejected with the circulating water, and some of the heat units are lost for feed-water purposes. If surface condensers be used with this type of engine, then it is necessary (*a*) to include an exhaust separator between the engine and condenser, so as to remove much of the oil carried over by the exhaust, and prevent its deposit on the condenser tubes, and (*b*) to treat the air pump discharge water before it enters the hot well by some chemical treatment as described in Chapter IV. This is unnecessary with turbo-generators, and surface condensers have many advantages with this type of plant.

Types of Condensers compared.—The following comparisons will be of use to the designer. In Table No. LXXIII. the comparative costs of various sizes of jet barometric and surface condensers are given, together with the quantities of circulating water required in each case.

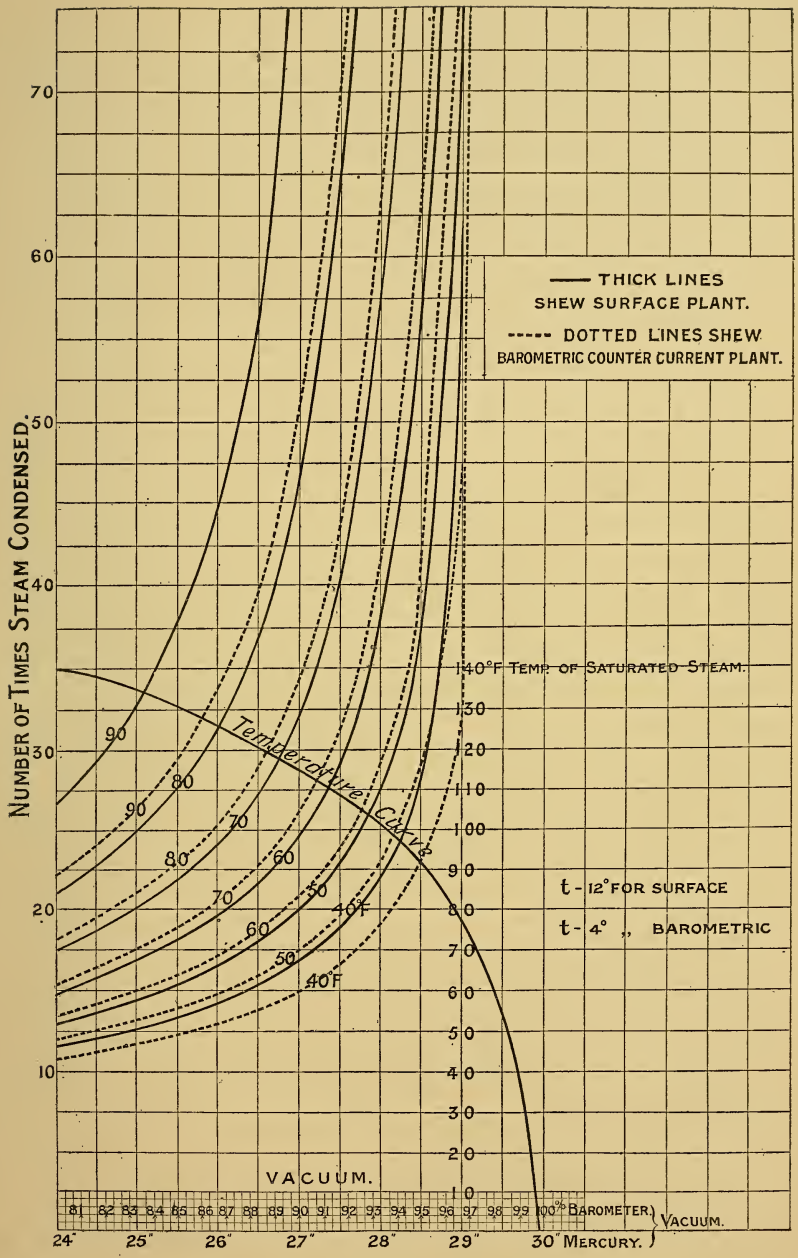

NUMBER OF TIMES STEAM CONDENSED.
70
60
50
40
30
20
10
THICK LINES
SHEW SURFACE PLANT.
DOTTED LINES SHEW
BAROMETRIC COUNTER CURRENT PLANT.
140°F TEMP. OF SATURATED STEAM.
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Temperature Curves
90
80
70
60
50
40°F
t - 12° FOR SURFACE
t - 4° ,, BAROMETRIC
VACUUM.
81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 % BAROMETER
VACUUM.
24" 25" 26" 27" 28" 29" 30" MERCURY.

FIG. 101.

TABLE LXXIII.

Barometer 30″. Injection water 60° Fahr.

Duty. Lbs. steam per hour.	Surface plants. Vacuum 28″.		Barometric plants. Vacuum 28¼″.	
	Approximate price.	Circulating water. Gallons per hour.	Approximate price.	Injection water. Gallons per hour.
	£		£	
5,000	425	19,800	350	15,960
9,000	550	32,400	460	28,800
16,000	750	57,600	600	51,600
25,000	1000	90,000	830	80,400
33,000	1225	120,000	1000	105,600
45,000	1625	162,000	1275	144,000
54,000	1850	195,000	1460	174,000

The barometric jet condenser may prove the most suitable in certain cases. The condenser has necessarily to be erected away from the engine, and there is a long and expensive pipe between the engine and the condenser, and a corresponding loss of vacuum at the engine due to pipe friction and air leakage, together with high pumping costs, owing to the water having to be lifted to the condenser level. The condenser is placed at such a height that the injection water and condensed steam flow from the condenser against the atmospheric pressure by gravity and the usual water extracting pump is replaced by a pipe from the bottom of the condenser to a small sealing tank which forms the barometric leg.

For small plants, therefore, especially where cooling towers are necessary, jet condensers either of the low level or barometric type may be adopted. For larger plants with reciprocating engines, either kind of condenser may be adopted to suit best the particular plant and locality, while for turbine plants and power houses of larger size, especially where there is a plentiful supply of circulating water, surface condensers have the advantage.

Cooling Towers and Ponds.—There are three kinds of cooling tower—

(*a*) Natural draught open type.

(*b*) Natural draught chimney type.

(*c*) Forced draught chimney type.

Natural Draught Towers.—The natural draught chimney type is that most usually adopted, it requires less ground space than (*a*),

and more than (*c*), but the power required to run a forced draught tower is prohibitive, and the natural draught chimney discharges the vapour at such a height—varying from 50 to 80 feet—as to obviate nuisance and rain. The level of the water inlet is usually about 25 feet from the tank water level.

Area required.—The area required for natural draught towers is 1 square foot to each 20 lbs. of steam condensed. This figure will suffice for a general preliminary estimate or design, but must be taken as only very approximate, since average atmospheric temperatures and average humidity of the atmosphere in any particular locality have to be considered. The circulating water required is about 60 gallons per square foot of ground area, the water being cooled from 95° Fahr. to 75° Fahr. This may be taken as a standard for natural draught towers.

Efficiency of Natural Draught Towers.—The efficiency of natural draught cooling towers depends upon—

(*a*) The maximum temperature of the injection or circulating water, which can be obtained by a counter-current jet condenser allowing the water to be discharged at practically the vacuum temperature. (Other things have to be considered when selecting the type of condenser, *ubi supra.*)

(*b*) The design, which should be such that a minimum quantity of water is in circulation to deal with the heat units dispersed per unit of time, as well as requiring only a minimum lift of water.

(*c*) The *effective* area of the cooling stack or shaft which should be a maximum proportion of the total area covered by the tower.

Cooling Ponds.—If plain cooling ponds are adopted (these can only be considered practicable for quite small plants) then an allowance is necessary of a minimum of 300 cubic feet of pond storage per H.P., and a surface of not less than 100 square feet per H.P., when the plant is running an average ten hours per diem, under average conditions of atmospheric temperature and humidity.

The cooling efficiency of ponds is sometimes increased by the use of revolving nozzles to spray the water, or by a series of weirs, or bundles of brushwood, so as to break up the water and expose it to the air.

Cooling towers are necessary for larger plants where artificial cooling is obligatory. These are sometimes of a wooden framework with wood sheeting, and fitted internally with distributing troughs and series of hurdles or laths, so as to break up and spray the falling water. It is better practice to spend a greater initial sum, and to build a more permanent shell for the tower. This may either be of reinforced concrete or of brick, as shown in Fig. 102, which illustrates one of the large reinforced concrete towers built for the Author at Bahia Blanca. The former is rather better practice, especially in countries liable to severe frosts. The structure should be designed to withstand a wind pressure of 40 lbs. per square foot, and since it offers a very large surface, this must be carefully checked.

Where the water supply is obtained from cooling towers a condenser should be used in which the temperature of the discharge water approaches within 5 per cent. of the vacuum temperature. Therefore the rise in the circulating water temperature will be 20°, equivalent to about 52 pounds of water per pound of steam condensed.

Cooling towers evaporate from 8 to 15 per cent. of the total water circulated in a run of about ten hours, according to the atmospheric temperature and humidity.

Local conditions of course differ, but for a hot climate, for example, it is usual to specify a duty of so many gallons of water per hour, the water to be cooled from 54° C. (129·4° Fahr.) to 36° C. (97° Fahr.), with an average temperature of the air of 32° C. (89·8° Fahr.) and 85 per cent. average humidity. Equivalent figures may be specified to suit a particular locality.

Fig. 103 is a series of curves given by J. R. Bibbins in a paper read before the American Society of Mechanical Engineers, which show the vacua possible with varying conditions of condenser and with fixed cooling tower performance.

Modern air pumps—such as the Le Blanc—make it possible to operate condensers on small temperature differences of from 2° to 5° Fahr., with a reasonable injection or circulating water ratio.

The smaller this difference is, the higher is the permissible maximum inlet temperature of the circulating water to the condenser and the air to the cooling tower for any given conditions.

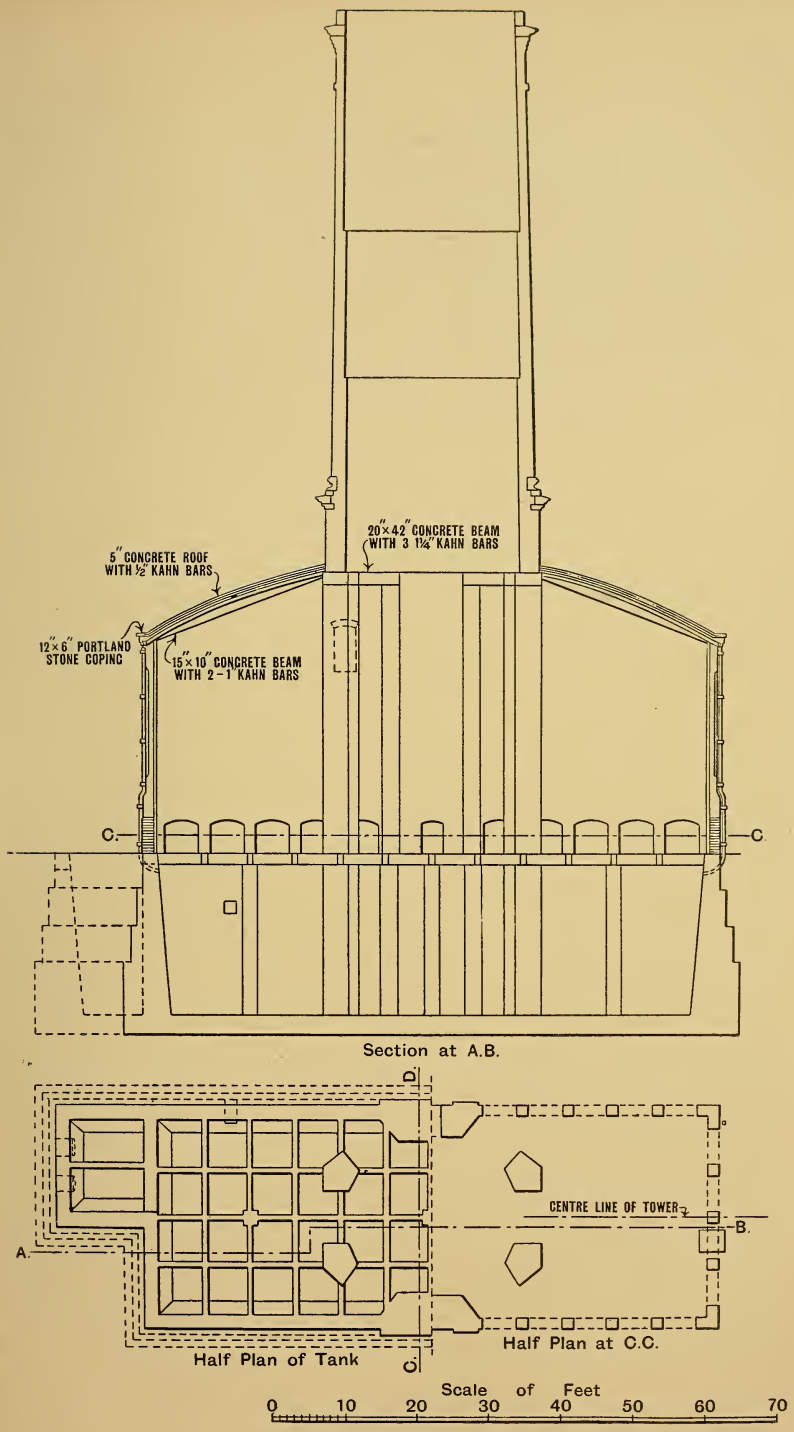

20″×42″ CONCRETE BEAM
WITH 3 1¼″ KAHN BARS
5″ CONCRETE ROOF
WITH ½″ KAHN BARS
12″×6″ PORTLAND
STONE COPING
15″×10″ CONCRETE BEAM
WITH 2–1″ KAHN BARS
C.
C.
Section at A.B.
A.
B.
CENTRE LINE OF TOWER
Half Plan of Tank
Half Plan at C.C.
Scale of Feet
0 10 20 30 40 50 60 70

FIG. 102.

Thus for a 28-inch vacuum, 20° difference of temperature in the condenser and 15° in the tower, the highest possible temperature of the outside air would be 65° Fahr. With warmer air the vacuum would fall.

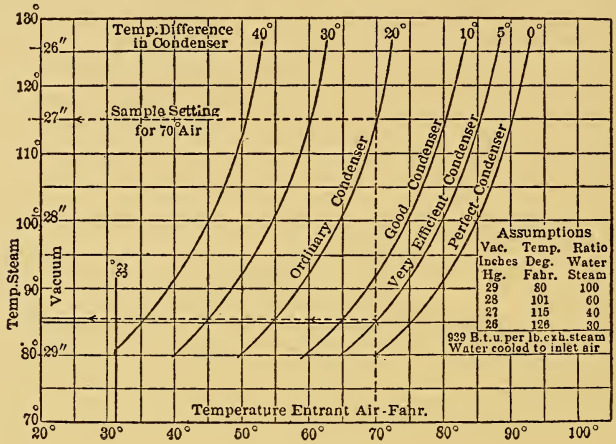


FIG. 103.

Construction of Cooling Towers.—The bottom openings admitting air to the tower should be fitted with louvres, to prevent the falling water from being splashed or blown out. All wood should be thoroughly seasoned and impregnated with a preservative compound, such as sideroleum, and weighed before and after treatment, to ensure an absorption of not less than 8 to 10 lbs. of compound by each cubic foot of timber applied under a pressure of 100 lbs. per square inch.

The internal distributing troughs and cooling hurdles are independent of the structure and easily renewable. Copper nails should be used, if nails are necessary; but, as a rule, in well-designed towers no nails are used. An access ladder is necessary to inspect the troughs and to adjust the flow of water in the distributing troughs.

The tank is of concrete, mixed in the proportion of 27 cub. feet of stone and 13½ cub. feet of sand to 6½ cwts. of cement. The inside, after being rendered smooth with cement, can be lined with two coats of bitumastic solution. This soaks into the pores and prevents the concrete from sweating after it has thoroughly set. The bottom of the tank should be laid with a fall to one corner,

and a small sump arranged at that point for emptying. Tanks have to be run out from time to time, so as to remove the impurities which will gather and concentrate at the bottom.

Steel cooling towers are also made both for natural and for forced draught. The life of the plates is necessarily shorter than brick or concrete towers, and, from the Author's experience with them, a good deal of scraping and painting is necessary, and they cannot compare, in durability, with the brick or reinforced concrete tower.

Tables LXXIV. and LXXV. give the areas and statistics of a series of towers. For the sizes, etc., of chimney natural draught cooling towers, see Appendix IV.

TABLE LXXIV.

NATURAL DRAUGHT OPEN TYPE COOLER.

(*a*) For medium cooling.

Reference No.	Capacity water per hour.	Ground space.		Total height.	Approximate foundations for average conditions.		Approximate weight.
		Length.	Width.		Excavations.	Concrete.	
	gallons.	ft.	ft.	ft.	cubic ft.	cubic ft.	tons.
1	2,000	13	15	20	880	660	$2\frac{1}{2}$
2	3,000	13	18	20	1050	700	3
3	4,000	13	21	20	1180	730	$3\frac{3}{4}$
4	5,000	13	24	20	1320	770	$4\frac{1}{2}$
5	6,000	18	18	20	1400	880	5
6	7,000	18	20	20	1480	920	$5\frac{1}{2}$
7	8,000	18	21	20	1590	955	6
8	9,000	18	23	20	1660	980	$6\frac{1}{2}$
9	11,000	18	24	20	1760	1020	$7\frac{1}{2}$
10	13,000	18	30	20	1950	1060	$8\frac{1}{2}$
11	15,000	18	33	20	2120	1130	$9\frac{1}{4}$
12	17,000	18	36	20	2300	1200	$9\frac{3}{4}$
13	20,000	18	41	20	2500	1270	11
14	22,000	23	32	20	2650	1410	11
15	24,000	23	34	20	2800	1490	$11\frac{1}{2}$
16	26,000	23	36	20	3000	1550	$12\frac{1}{4}$
17	28,000	23	39	20	3200	1630	$13\frac{1}{4}$
18	30,000	23	41	20	3350	1700	14
19	35,000	23	46	20	3550	1800	16
20	40,000	23	52	20	4100	1920	18
21	45,000	23	57	20	4600	2050	20
22	50,000	23	62	20	4950	2200	22
23	55,000	23	68	20	5300	2330	$24\frac{1}{2}$
24	60,000	23	73	20	5650	2620	$26\frac{1}{2}$
25	65,000	23	79	20	6000	2760	$28\frac{1}{2}$
26	70,000	23	84	20	6400	2900	$30\frac{1}{2}$
27	75,000	23	90	20	6700	3040	$32\frac{1}{2}$
28	80,000	23	95	20	7100	3200	$34\frac{1}{2}$
29	90,000	23	106	20	7400	3320	$36\frac{1}{2}$
30	100,000	23	117	20	8200	3550	$38\frac{1}{2}$

TABLE LXXV.

(*b*) For very low cooling down to air temperature with low humidity.

Reference No.	Capacity water per hour.	Ground space.		Total height.	Approximate foundations for average conditions.		Approximate weight.
		Length.	Width.		Excavations.	Concrete.	
	gallons.	ft.	ft.	ft.	cubic feet.	cubic feet.	tons.
1	400	13	13	20	700	630	2¼
2	800	13	16	20	885	690	2¾
3	1,200	13	20	20	1060	740	3½
4	1,600	13	24	20	1240	795	4½
5	2,000	13	28	20	1410	810	5
6	3,000	13	38	20	1770	890	7
7	4,000	13	47	20	2120	960	8¾
8	5,000	18	33	20	2120	1060	9¼
9	6,000	18	38	20	2300	1160	10¼
10	7,000	18	43	20	2470	1240	11½
11	8,000	18	47	20	2550	1300	13
12	9,000	18	52	20	2700	1350	14½
13	10,000	18	57	20	2830	1410	16
14	11,000	23	44	20	3200	1590	16
15	12,000	23	47	20	3350	1700	17
16	13,000	23	51	20	3530	1770	18

Humidity.—As the efficiency and size of cooling towers depend on the average humidity of the atmosphere of the district where the plant is to be installed, it is well to know what these meteorological data are. To enable the designer to ascertain this, the following formula and Table No. LXXVI. may be used, the only instruments required being a wet and dry thermometer and barometer.

Let F denote the vapour pressure corresponding to the temperature T of the dry bulb (in degrees Fahrenheit), and let F′ be the vapour pressure corresponding to the reading T′ of the wet bulb. Also let L denote the height of the barometer in inches of mercury. Then the relative humidity

$$\text{R.H.} = \frac{F' - L(T - T')}{2610 \times F}.$$

Materials used in the Construction of Condensers.—The following notes of materials used will be of use in specifying for condensers.

Cast iron to be well and cleanly cast of good grey-coloured,

close-grained pig iron of such a mixture to yield the best results in strength and toughness, and such that a test bar 3 feet 6 inches in length and 2 inches by 1-inch cross section when placed on bearings 3 feet apart will bear a load of 30 cwt. without breaking, suspended from its centre, and with a deflection of not less than $\frac{5}{16}$ inch.

TABLE LXXVI.

A Method of determining the Relative Humidity of the Air.

Temperatures Centigrade.	Pressures in millimetres of mercury.	Temperatures Fahrenheit.
0	4·60	32
5	6·53	41
10	9·17	50
15	12·70	59
20	17·39	68
25	23·55	77
30	31·55	86
35	41·82	95
40	54·91	104
45	71·39	113
50	91·98	122
55	117·47	131
60	148·70	140
65	186·94	149
70	233·09	158
75	288·51	167
80	354·64	176

Instruments required—Barometer and Mason's Hygrometer.

Tube plates, etc., for surface condensers to be of best rolled brass, containing 62 per cent. copper, 37 per cent. zinc, and 1 per cent. tin.

Tubes for surface condensers to be of solid drawn brass, containing 70 per cent. copper, 29 per cent. zinc, and 1 per cent. tin. These are usually $\frac{3}{4}$-inch external diameter, and 0·048 inch in thickness.

Tubes should always be carefully tinned both inside and outside.

The following tests for tinning will be of use.

The samples, having been cleaned with alcohol or ether, are immersed for one minute in hydrochloric acid. They are then

rinsed in clean water and immersed in sodium sulphide solution (specific gravity 1·142) for a period of 30 seconds, and again washed. They are then examined by a magnifying glass. This is repeated several times, until blackening of the wire becomes clearly visible. The number of such operations required to produce this blackening is noted, and is taken to represent the measure of efficiency of the tinning.

Gunmetal parts for air pumps, etc., are usually made from a mixture of 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc.

Manganese bronze rods, etc., are usually made from a mixture having a tensile strength of 29 tons, elastic limit 13·4 tons, and elongation of 20 per cent. in a test length of 2 inches.

Tests of condenser bodies, etc., are usually made by subjecting them to a hydraulic pressure of 30 lbs., and motors and pumps are run under the usual conditions to ascertain power absorbed, temperature rise, etc.

CHAPTER VIII

INTERNAL COMBUSTION ENGINES

THE internal combustion engines available are gas driven (coal gas, producer gas, coke oven or blast furnace gas) and oil driven.

Gas Engines.—Gas engines are made either of the 4-stroke, Otto cycle, *i.e.* one impulse in every four strokes for each single acting cylinder, or the 2-stroke with an impulse per revolution. Gas is admitted to the cylinder with the correct volume of air previously admitted, compressed and then ignited at the beginning of the impulse stroke. The piston in its return drives out the waste or exhaust products; a new charge is drawn in on the third stroke, and the fourth (or second return) stroke compresses the new mixture of gas and air. A single cylinder engine thus has only one impulse stroke in every two revolutions, and thus has an uneven angular velocity. To improve the steadiness two or more cylinders are used, especially for driving alternators and for parallel running. In the 2-stroke cycle engines, usually adopted with the larger types with double-acting cylinders, the exhaust valves are opened at the end of each impulse stroke, and the waste gases expelled by a forced or induced draught of air, and the cylinder scavenged. The cylinder is then ready for the next charge, which is compressed by the return stroke.

Gas engines are made in vertical types, as shown in Fig. 104, or more generally, in the larger engines, in horizontal types with tandem double-acting cylinders, as shown in Fig. 105.

Gas engines are incapable of carrying more than 10 per cent. overload, and this must be borne in mind by the designer.

A report was presented in 1907 by an influential committee appointed by the American National Electric Light Association, on the use of large gas engines for driving electrical generators.

Some extracts from this report are included herein, and the following paragraphs are reprinted from this report, and suffice to show to what extent the gas engine has been and is being adopted in large power plants. The Committee states: "The

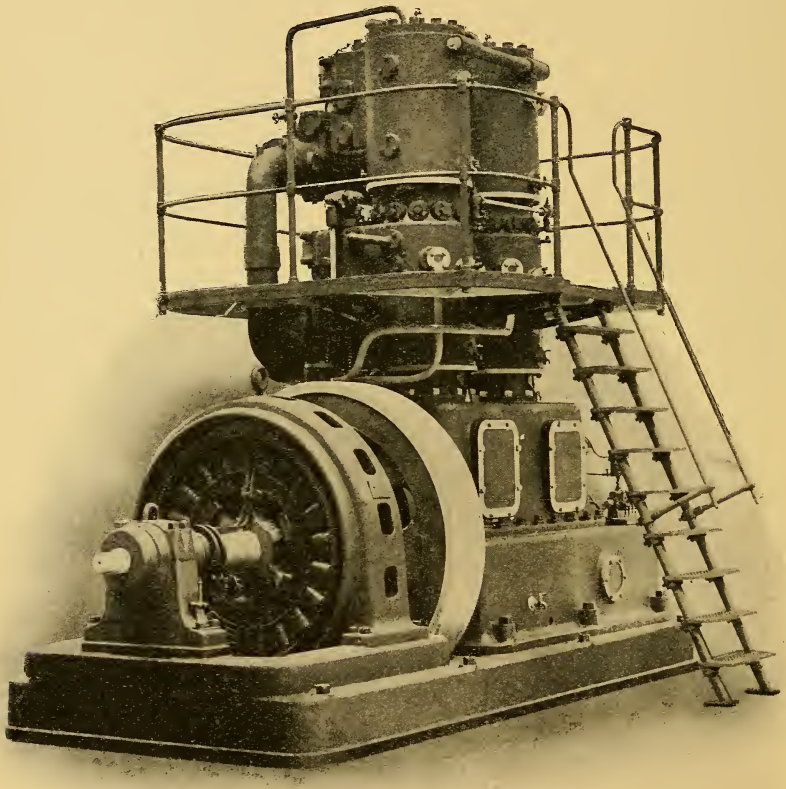


Fig. 104.

efficiency of the combined gas engine and producer is higher than that of a combined steam plant of boilers and steam engines, or boilers and steam turbines. There are to-day installed and building in this country at least 300,000 H.P. in large units. The enormous investment, as shown above, indicates the assurance

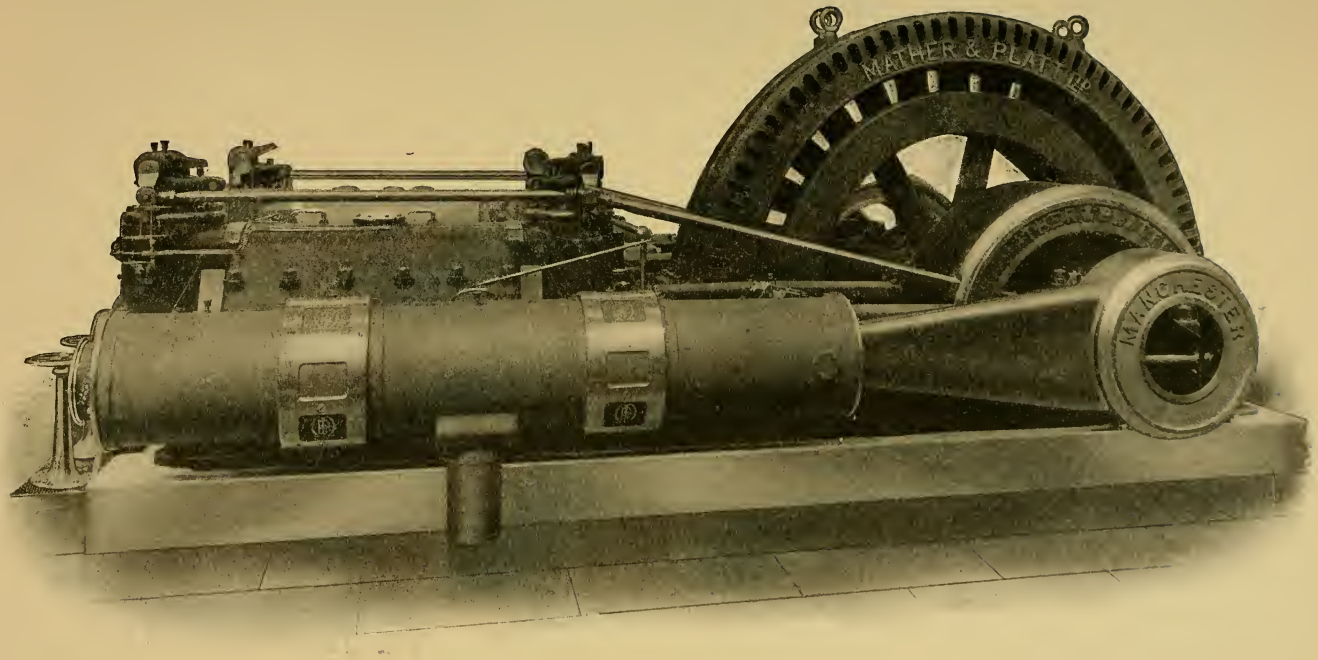


Fig. 105.

with which the operators of this class consider the reliability of the gas engine. . . . Continuous operation can be expected with no more attention than that given to steam engines of equal capacity.

"While at present the Committee believes that the cost of gas engines is much in excess of that of steam engines of the same capacity; it also believes that it is possible to builda combined producer and gas engine plant for costs approximately that of the combined boiler and steam engine plant, when all auxiliaries and buildings are included."

The manufacture of gas engines is an established industry on a large scale in Europe, particularly in Germany, where they are largely used in connection with blast furnace products, to drive generators which supply power to the rolling mills and auxiliary machines in the steel works.

There are two salient points to be borne in mind—

(1) The natural fuel gas engine is very much more economical than any combined steam plant; thermal efficiencies at full load of 30 per cent. are obtainable as against a more usual figure of 12–15 per cent. in steam plants.

(2) The capital cost of a combined producer and gas engine is higher than the equivalent amount of boilers, steam engines, and auxiliaries.

Extracts from the above-mentioned report show that the cost of repairs is not materially different from the cost of steam plant; the cost of labour is practically the same, though the reliability of the plant is certainly not so pronounced as that of good steam plant, and this factor must be considered when designing any power house. Generally, it may be said that when the cost of fuel is low, with a low annual load factor, gas engines will not compare economically with steam plant. Where fuel is costly, and where there is a high annual load factor, then there is a strong case for gas-driven plant. A combination of both steam and gas plant will have much to commend it, for the gas-driven sets can be utilized on the parts of each day curve giving the highest load factor, while the steam plant can be used on those parts of the curve which have a shorter period and more uneven load, besides which there is a reserve of steam plant which will mitigate the present somewhat less reliability of the gas plant.

J. R. Bibbins (*American Institute of Electrical Engineers*, vol. 22) gives the following table (No. LXXVII.) of calorific values :—

TABLE LXXVII.

	Approximate calorific value of gas.	B.Th.U. per cubic foot of mixture.
1. Natural gas	1000	91·0
2. Coal gas	650	91·7
3. Water gas	300	88·0
4. Carburetted water gas . .	600	92·0
5. Producer gas	120-145	60-68
6. Coke oven gas	600	90·0
7. Blast furnace gas	90	53·0

The Westinghouse Company have published the following useful notes on gases :—

TABLE LXXVIII.

COMMERCIAL POWER GASES.

Gas.	Approximate order of value.	Origin.	General characteristics.
Natural gas	1	Results from vegetable decomposition	Ideal power gas. Rich, pure, rather slow burning. Requires no cleaning
Producer gas	2	Obtained from coal, coke, peat, lignite, wood or straw. Largely an incomplete oxidation of carbon to CO by means of a steam air blast. Steam decomposes into free hydrogen. Some CO_2 formed	Cheapest and best of artificial fuel gases, clean and comparatively slow burning. Made from any grade of fuel
Bituminous producer gas	3	Bituminous coal. Breaking up of volatile hydrocarbons, and conversion of fixed carbon and CO	Richest of producer gases. Tar distillate difficult to remove. Most grades of coal suitable, including slack, lignite, and wood

Gas.	Approximate order of value.	Origin.	General characteristics.
Anthracite producer gas	4	Anthracite coal. Practically no volatile gases. Conversion of fixed carbon	Gas free from tar—requires little cleaning. Excellent power gas
Blast furnace gas (bye-product)	5	Bye-product of blast furnaces. Conversion of fixed carbon in coke into CO by air blast. Some CO_2 formed	Gas very dusty and sluggish. Difficult to clean except by mechanical process. Excellent gas for engines with high compressions
Coke oven gas (bye-product)	6	Liberation of volatile gases contained in coal in closed chambers without combustion	Gas should be drawn off during early part of coking process. Good gas, rather high in hydrogen and sulphur. Requires much purification
Coke producer gas	7	Coke or charcoal. No volatiles. Conversion of fixed carbons	Gas practically clean, except for dust. Most suitable for small producers. Fuel rather expensive
Coal gas .	8	Destructive distillation of coal in closed retorts	Excellent gas, resembling natural gas. Not hard to clean. Manufacturing costs usually too high for general power purposes
Oil gas .	9	Vaporization from crude oil. Used to enrich water gas	Very rich in heavy hydro-carbons. Liable to carbon deposits. Seldom used for power except in small petrol engines
Water gas	10	Decomposition of steam on incandescent coke. Hydrogen, freed carbon burned to carbon monoxide	Pure gas. Excess of hydrogen causes pre-ignition, therefore unsuitable for gas engines. More suitable if enriched with oil gas

The chemical composition of various utilizable gases is given in Table No. LXXIX., and should be considered in conjunction with Table No. LXXVIII.

TABLE LXXIX.

CHEMICAL COMPOSITION OF GASES.

Composition.	Natural gas.	Coal gas.	Coke oven gas.	Mond producer.	Coke or anthracite producer gas.	Bituminous producer.	Blast furnace gas.	Chemical values at 32° F. and 760 mm. pressure.	
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	
CO_2	—	0·60	0·83	14·6	3·40	4·0	11·5	—	CO_2
C_6H_6	0·31	1·00	0·45	—	—	—	—	4011	C_6H_6
C_2H_4	92·60	2·47	3·20	—	0·80	—	—	1473	C_2H_4
CH_4	—	34·76	36·60	5·3	2·50	9·60	—	1065	CH_4
CO	0·50	4·23	3·00	10·30	25·90	25·00	27·5	341	CO
O_2	—	0·49	1·10	0·50	—	0·60	—	—	O_2
H_2	2·18	52·22	52·10	23·50	9·20	19·40	5·0	343	H_2
N_2	4·41	4·23	2·70	55·80	58·20	41·40	60·0	—	N_2
Sp. gr.	—	0·46	0·42	—	—	—	—	—	—
B.Th.U. Calorific value	870–980	635	400–650	164	125–145	135–200	85–115	—	—
Bye-products	—	Ammonia, tar products. Benzol. Coke.	Ammonia, tar products. Benzol. Coke.	Sulphate of ammonia tar.	—	Sulphate of ammonia	—	—	—

Blast Furnace and Coke Oven Gas.—Since power houses for all purposes of electrical productions are properly included in this work, attention will first be paid to the special adaptation of gas engines to coke oven and to blast furnace gases. Here the otherwise waste gases are economically made use of to develop electrical energy for the supply of the works, and sometimes also of the surrounding district. As will be seen in Table No. LXXIX., coke oven gas has a high calorific value, but the blast furnace gas has a much lower calorific value. Larger cylinders are therefore required in engines run from blast-furnace gases.

Fig. 106 shows an installation of two single tandem 2200 H.P. Ehrhardt & Sehmer engines at the Holsch Iron and Steel Works, Germany, run from blast-furnace gas.

Horizontal Gas Engines.—The following Table, No. LXXX., sets out the standard sizes and leading particulars of Korting gas engines, as made by Messrs. Mather & Platt, of Manchester, England.

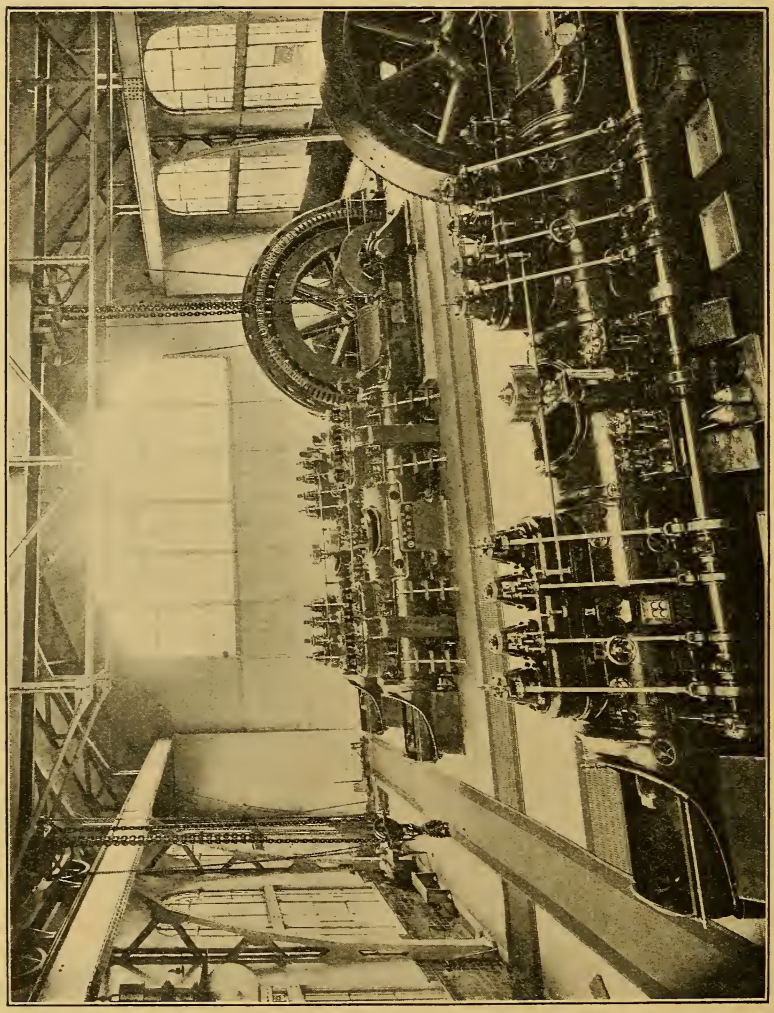


FIG. 106.

TABLE LXXX.

KORTING TWO-CYCLE GAS ENGINES FOR WORKING WITH PRODUCER GAS OF 150 B.TH.U. PER CUBIC FOOT BLAST FURNACE, COKE OVEN AND OTHER GASES.

Fly-wheels for cyclic irregularity of 1 to 100.

Single Cylinder.

B.H.P.	R.P.M.	Approximate overall dimensions. Length.		Breadth.		Height.		Weight of fly-wheel.	Approximate net weight.	Approximate diameter of pipe connections to each cylinder.			
		met.	ft. ins.	met.	ft. ins.	met.	ft. ins.	tons.	tons.	mm.	ins.	mm.	ins.
150	175	5·33	17 6	2·74	9 0	1·3	4 3	4½	16	152	6	229	9
250	135	6·71	22 0	3·2	10 6	1·52	5 0	7½	25	203	8	280	11
300	115	7·62	25 0	3·5	11 6	1·68	5 6	9	30	229	9	330	13
400	110	8·53	28 0	3·81	12 6	1·75	5 9	10	45	254	10	381	15
500	110	8·53	28 0	3·81	12 6	1·75	5 9	13	50	280	11	406	16
600	100	9·75	32 0	4·88	16 0	1·98	6 6	16	75	305	12	457	18
700	95	9·75	32 0	4·88	16 0	1·98	6 6	20	85	356	14	508	20
800	90	11·58	38 0	5·49	18 0	2·29	7 3	24	120	406	16	559	22
1000	80	12·19	40 0	5·94	19 6	2·29	7 3	32	135	476	18¾	660	26
						Twin Cylinders.							
300	175	5·33	17 6	4·57	15 0	1·3	4 3	4½	27½	152	6	229	9
400	170	5·33	17 6	4·72	15 6	1·3	4 3	6	31	179	7	254	10
500	135	6·71	22 0	5·33	17 6	1·52	5 0	7½	42½	203	8	280	11
600	115	7·72	25 0	6·10	20 0	1·68	5 6	9	53	229	9	330	13
700	135	7·62	25 0	6·10	20 0	1·68	5 6	9½	54	229	9	330	13
800	110	8·53	28 0	6·71	22 0	1·75	5 9	10	80	254	10	381	15
1000	110	8·53	28 0	7·01	23 0	1·75	5 9	13	88	280	11	406	16
1200	100	9·75	32 0	8·23	27 0	1·98	6 6	16	134	305	12	457	18
1400	95	9·75	32 0	8·53	28 0	1·98	6 6	20	150	356	14	508	20
1600	90	11·58	38 0	8·84	29 0	2·29	7 3	24	216	406	16	559	22
2000	80	12·19	40 0	9·14	30 0	2·29	7 3	32	238	476	18¾	660	26
						Four Cylinders.							
1000	135	9·45	31 0	5·33	17 6	1·52	5 0	13	65½	203	8	280	11
1250	115	10·67	35 0	6.10	20 0	1·68	5 6	16	82	229	9	330	13
1600	110	11·88	39 0	6·71	22 0	1·75	5 9	24	128	254	10	381	15
2000	110	11·88	39 0	7·01	23 0	1·75	5 9	32	145	280	11	406	16
3000	95	13·7	45 0	8·53	28 0	1·98	6 6	42	225	356	14	508	20

As in all gas engines there is a large quantity of waste heat in the exhaust gases, exhaust boilers can be fixed for the utilization of this heat, which will evaporate from 2 to 2·75 lbs. of steam per brake-horse power of the gas engine, at a pressure of from 50 to 80 lbs. These are usually erected close to the exhaust outlet from the main cylinder. It is usual to fix these boilers with a special grate so that hand firing may be resorted to when the main gas is not running. Either coal, or the refuse coal tar from the gas plant, may be used as fuel during such periods.

The average cost of large gas engines may be taken as approximately £5·5 per B.H.P.

Fig. 107 shows an installation of gas engines, some of 1300 H.P., and some of 3000 H.P., at the Heinitz mines in Germany, driven by coke oven gas and driving alternators in parallel. This is part of an ultimate 12,000 H.P. plant.

At Messrs. Cockerill's gas station, with blast furnace gas, on an annual output of 24,000,000 units and a load factor of 50 per cent., the works cost per B.H.P. hour were only 0·047*d*.

The analysis of costs was as follows:—

(*a*) Labour, engine attendants, generator and switchboard men, and superintendent .	45 per cent.
(*b*) Lubrication	20 „
(*c*) Cleaning, upkeep, and repairs	35 „
	100

This does not include any allowance for the depreciation of plant.

The following notes will be of use to the designer in estimating the operating costs of any gas plant, but are particularly based on the above engines, on practical experience put at the Author's disposal through the courtesy of Messrs. Galloways, Ltd.

Bases for estimating operating costs—

Heat Consumption.—

Maximum load	.	9,500	B.Th.U.	per	B.H.P. hour
Normal full load	.	10,000	„	„	„ „
¾ „	. .	11,250	„	„	„ „
½ „	. .	13,500	„	„	„ „
¼ „	. .	21,000	„	„	„ „

Efficiency of producers.—75 per cent.

Oil Consumption.—About 1 gallon per 4000 B.H.P. hours, assuming the engine at nearly full load. But little reduction with decreased load. Engine and generator only.

Oil and Stores.—For the whole plant, allow about double the cost of oil for reciprocating steam plant.

Water.—About 6·5 gallons per B.H.P. hour if at 50° Fahr.

„ 7·75 „ „ „ „ 60° „
„ 9·75 „ „ „ „ 70° „
„ 12 „ „ „ „ 80° „

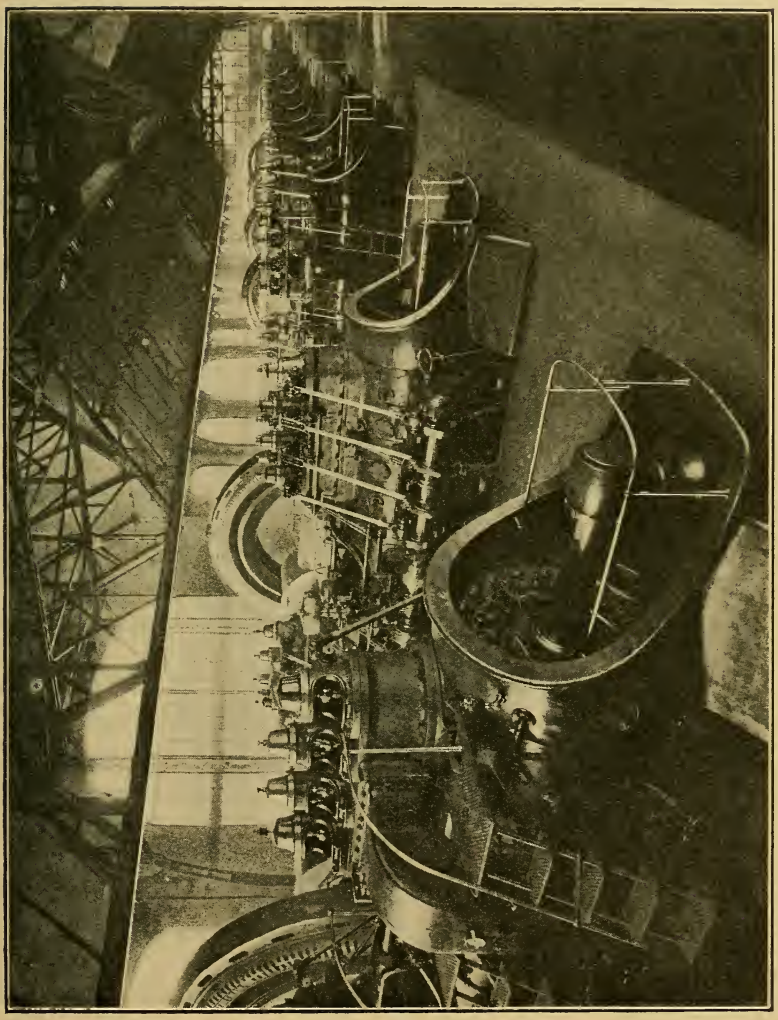


FIG. 107.

The above figures are based on normal full load. They fall off at light loads, but not in proportion to the load.

When a cooling tower is employed of the open type the make-up water is usually about 8 per cent. of the total. The exit temperature of water from engine should not much exceed 115° to 125° Fahr.

Labour.—One greaser is allowed to each engine of large size, together with fair proportion of skilled supervision.

Repairs and Maintenance.—Varies between 1 and 2 per cent. of initial capital outlay on engines, in large German steelworks. The higher value is met with in engines of older and inferior designs. For a well-kept power station this item (for gas engines only) should not exceed 1½ per cent.

Depreciation.—This depends on how the engines are worked and maintained, and upon the load factor of the plant. It should not exceed 4 to 5 per cent. if well looked after. It may generally be taken at from 3 to 4 per cent. over the whole plant.

Interest.—This depends, of course, upon conditions: *e.g.* whether municipal or private, and also upon the standing of the company. Interest is usually calculated at from 3¾ to 5 per cent.

The gas engine shown in Fig. 108 represents those manufactured by Messrs. Galloways, Ltd., of Manchester, England, and Messrs. Ehrhardt and Sehmer, Germany.

These are double-acting four-cycle engines with horizontal cylinders arranged either in single or double tandem form. The cylinders embody some most important practical details, which have been arrived at as the result of long experience, particularly in the design of the end covers, and gas inlets, relieving the great internal stresses, due to casting or unequal expansion, and preventing their concentration on weak points in the structure. The cylinder body is cast in two parts bolted together circumferentially and fitted over a liner. The water jacket is enclosed by a rolled-steel band which transmits no stress and can be easily removed without disturbing any other part, so as to facilitate a complete inspection and cleansing of the water jacket. The cone-shaped pistons and rods are water cooled. Ignition is on the "Lodge" high-tension system, which is in duplicate at each cylinder end, and is unaffected by moisture or even by carbonized oil or deposit.

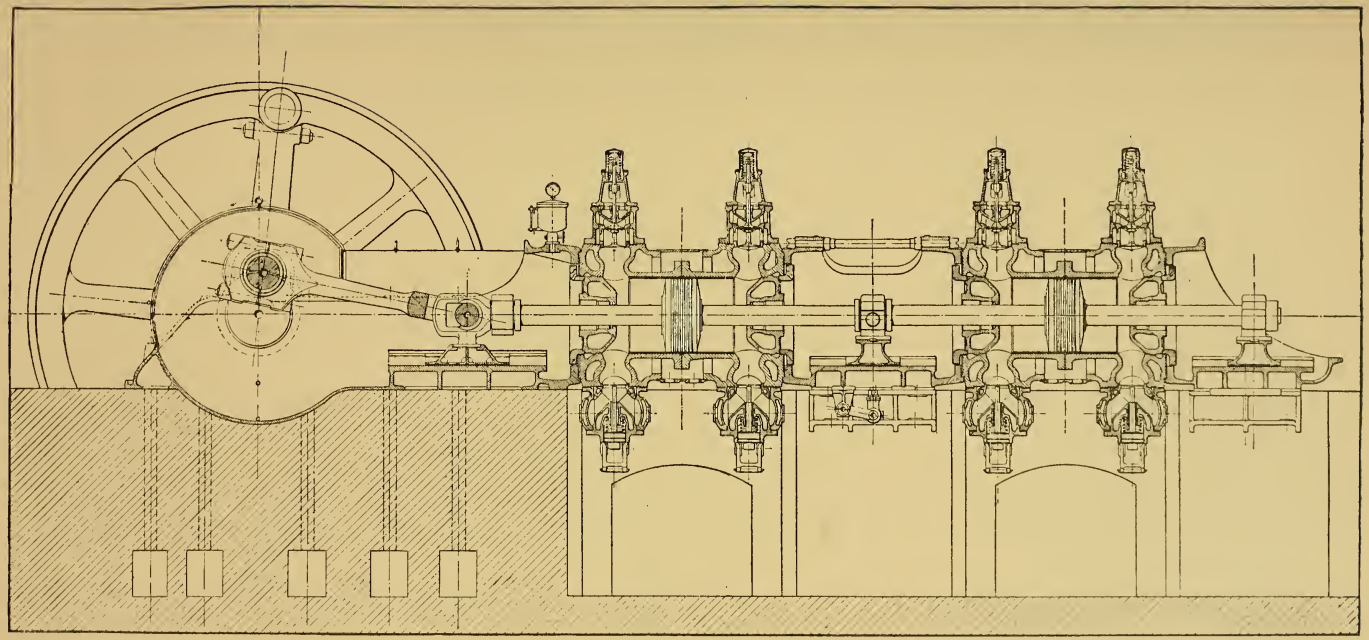


Fig. 108.

Governing is effected by throttling the supply of gas. The gas-admission valve is carried by the spindle of the main-admission valve, so that these two valves close tight even should the valve seats be unequally worn, thus preventing back firing. The engines are, of course, started by compressed air. Table No. LXXXI. sets out the approximate particulars of these engines, and Table No. LXXXII. the main dimensions. A constant progress is being made in these engines, and a set of standard engines is now being made by this firm approximately of the same output as those given in Table No. LXXXI., but with 5 per cent. less weight and cost, and 5 per cent. approximate higher speed.

TABLE LXXXI.

STANDARD GALLOWAY GAS ENGINES.

Ehrhardt & Sehmer Patents.

B.H.P.		Revs. per min.		Weights in tons, approx.			Approximate price, erected.	
Steady continuous load.	Maximum load.	A.C. 50 periods.	D.C.	Heaviest single piece.	A.C. engine and fly-wheel.	D.C. engine and fly-wheel.	A.C.	D.C.
							£	£
500	600	150	150	8·5	82	74	4270	4020
630	780	136	136	12	111	100	4940	4600
750	925	125	125	15·2	136	122	5430	5050
880	1080	107	110	21·5	170	152	6640	6170
1100	1340	100	100	28·5	225	200	8090	7520
1400	1715	94	95	34·0	285	250	9490	8820
1800	2200	94	90	44·0	365	325	10,950	10,100
2000	2400	94	90	—	414	374	11,880	11,030
2200	2600	94	90	—	—	—	—	—

The following notes on the above Table may be found useful:—

(*a*) A.C. speeds depend upon periodicity, and must comply with the formula—

$$\text{R.P.M} = \frac{120 \times \text{periods}}{\text{No. of poles}}$$

(*b*) The number of poles must be divisible by 2 (or 4 if the magnet ring has to be divisible into quarters).

(*c*) The above B.H.P. are based on A.C. speeds in the second

column. At any other speed the B.H.P. will be affected proportionally to the change of speed.

(*d*) The usual rating for two hours' overload test is in excess of the steady continuous load by from 7 to 10 per cent., according to the cleanliness of the gas and also of the engine cylinders and jackets.

(*e*) The approximate prices in Table No. LXXXI. include an average allowance for packing, carriage by rail, and erection on site within Great Britain.

(*f*) The engine prices and weights include :—

Engine and crankshaft.

Fly-wheel.

Holding down bolts and plates.

Lubrication pumps, oil shields, etc.

Standard air, gas and exhaust receivers and piping within the engine house.

Barring gear (hand, steam, or electric as suitable).

Pump-driven off engine shaft for supplying cooling water under pressure to engine, but not air compressor for starting.

Fig. 109 shows the principal dimensions H, G, I, and K referred to in Table No. LXXXII., from which the floor space can be obtained for the engines given in Table No. LXXXI.

The recent researches of Clerk, Callendar, and Hopkinson on the specific heat of gases at high temperatures, and particularly of the products of combustion in a gas engine, have reduced the marginal thermal efficiency which designers were hoping to obtain in future gas engines. The theoretical limit is about 35 per cent., and the efficiency of the present engines is some 30 per cent., leaving only a possible improvement of 5 per cent. The question is one of compression in the cylinder. The degree of compression in engines run by producer gas is 140 lbs. or less per square inch, and 180 lbs. when supplied with blast furnace gas containing only 1 or 2 per cent. of hydrogen. If the compression is carried beyond this point, then spontaneous combustion takes place by reason of the hydrogen present. Thus the gain in efficiency due to super compression is not great in engines employing the 4-stroke Otto cycle, and there is a tendency to develop along the 2-cycle line, with an increase of output as would be expected, though not

necessarily with an increase of efficiency; owing to the rejection of the gases to exhaust at a pressure considerably above atmospheric pressure, a great deal of heat energy is lost in the exhaust gases.

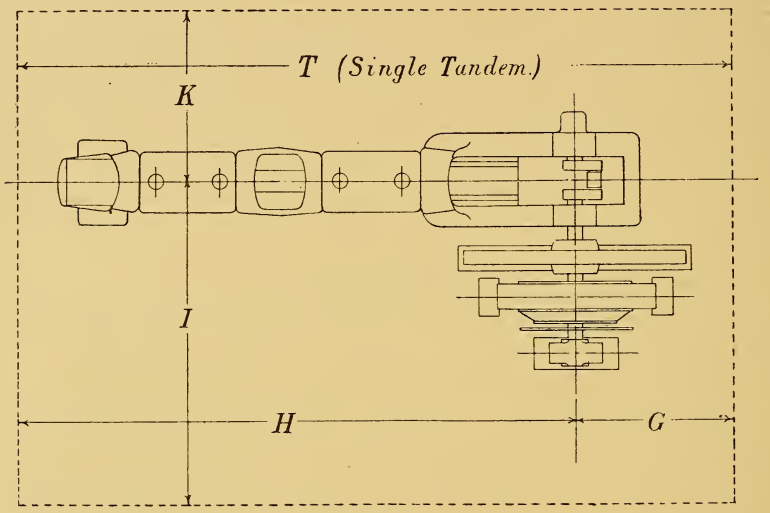


FIG. 109.

FLOOR SPACE OF GALLOWAYS, LTD., GAS ENGINES.

TABLE LXXXII.

	Engine-room.			Floor area.			
Engine B.H.P.	500–600.	630–780.	750–925.	880–1080.	1100–1240.	1400–1715.	1800–2200.
	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.
H	40 7	42 1	45 0	49 6	52 2	58 9	62 2
G	10 8	11 8	12 4	13 2	14 9	14 9	14 9
I	10 6	11 6	12 2	13 6	14 1	14 9	16 5
K	9 6	11 2	11 6	12 2	13 2	13 6	14 5

Andrews gave some useful curves in 1909, which the Author is permitted to produce herein, in Figs. 110–112.

The reduction of the cyclic irregularity is of great importance.

In Fig. 110 curve A shows the positive pressure in lbs. upon the crank pin throughout the impulse stroke due to the expansion of the gases. The connecting rod is assumed to be of infinite length. B shows the negative pressure due to the compression throughout the compression stroke. C is the back pressure due to the effort prior to opening the exhaust valve. D shows the positive and negative pressures due to inertia of moving parts. E represents the negative pressure resulting from the external

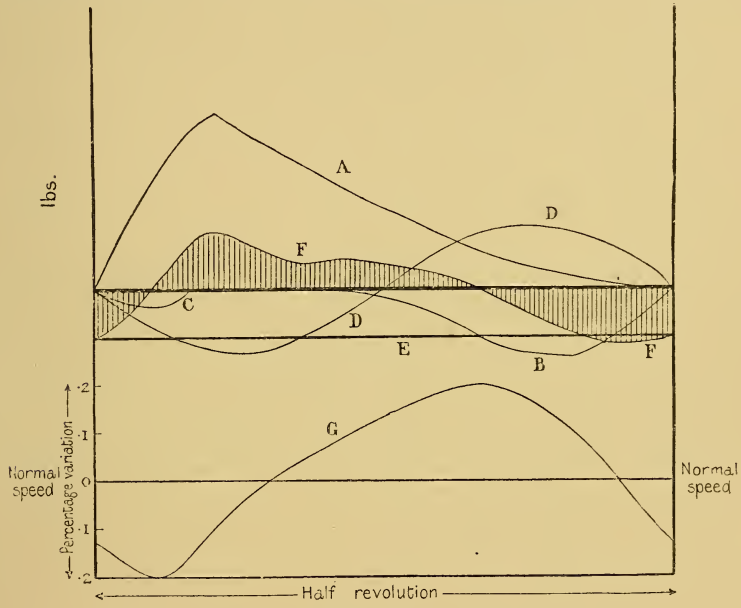


FIG. 110.

load plus the engine friction. F is the resultant fluctuation of crank effort due to the above forces. The area above zero line is the energy put into the fly-wheel, and that below the zero line the energy given out by the fly-wheel, the algebraic sum of which is, of course, zero. G is the variation of angular velocity throughout the stroke, and is equal to $\frac{I}{F}QW$

where W = normal angular velocity in radians per second,
Q = percentage fluctuation specified,
I = moment of inertia of fly-wheel.

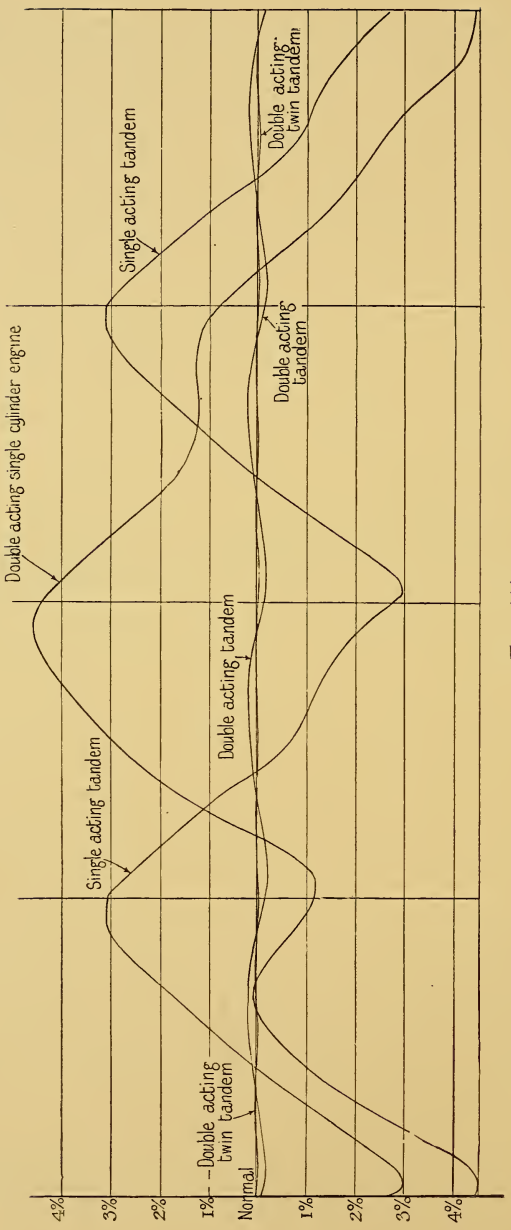

Double acting single cylinder engine
Single acting tandem
Double acting twin tandem
Double acting tandem
Single acting tandem
Double acting tandem
Double acting twin tandem
Normal
4%
3%
2%
1%
1%
2%
3%
4%

FIG. 111.

Fig. 111 shows the fly-wheel effort necessary to ensure the cyclic irregularity not exceeding $\frac{1}{250}$ or 0·004 for various types of gas engines.

Fig. 112 shows the capital costs of horizontal slow-speed gas engines and direct coupled generators erected complete with pipe-work and foundations. The figure also shows the capital cost for an equivalent output by a number of 500 H.P. units.

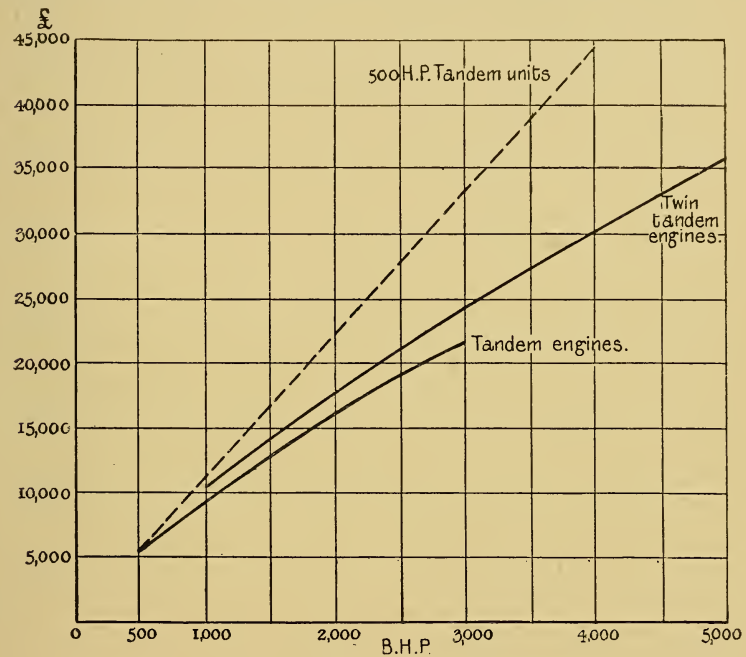


Fig. 112.

Vertical Gas Engines.—The Westinghouse Company have made vertical gas engines for many years, and these have reached a high degree of excellence. This type consists of a single-acting engine with either 2, 4, 6, or 8 cylinders, operating on the Otto or four-cycle period. The suction stroke of one cylinder of a pair is the working stroke of the other cylinder, so that the shaft receives one, two, three, or four impulses per revolution according to the number of cylinders. The inertia of each cylinder line is absorbed by compression in one or other of the cylinders on every up stroke,

and by a buffer cylinder on every down stroke. With a 6-cylinder engine the mechanical efficiency claimed is 85 per cent. and the thermal efficiency 26 per cent. calculated on B.H.P. Under average atmospheric conditions approximately 12 gallons of water per B.H.P. per hour is required to be circulated through the cylinder and cover jackets at a pressure of 20 lbs. per square inch and with an inlet temperature not exceeding 70° Fahr. The engines are started with compressed air, these equipments being provided with the engines, when necessary.

Fig. 113 shows an 8-cylinder Westinghouse gas engine direct coupled to a direct current generator. The makers guarantee a consumption not to exceed $1\frac{1}{4}$ lbs. of bituminous coal of fair calorific value per B.H.P. hour, or 1 lb. of anthracite per B.H.P. hour for the larger sizes.

Table No. LXXXIII. sets out the sizes and approximate prices of the Westinghouse vertical engines.

Starting Compressors.—Compressors are frequently adopted for starting up gas engines, or in electrical power houses motor barring sets could be introduced run from auxiliary batteries, or a small independent steam set can be installed fed from a small auxiliary boiler range from which all the auxiliaries can be run, such as the blowers, centrifugal cleaners, etc.

Producer Gas.—Large producers for utilizing bituminous coal have not been entirely satisfactory in the United States and in Germany, probably because the class of coal available contains a far greater percentage of ash than the bituminous coal obtainable in England, and is, therefore, more disposed to clinker. Bituminous coal contains a greater proportion of hydrogen than anthracite, and too high a percentage of hydrogen is likely to cause back firing or pre-ignition if the compression is carried beyond a certain critical point. Engines, therefore, have to be built so as to allow for a smaller degree of compression in such cases. Anthracite or other similar kinds of high-carbon coal are to be preferred, the calorific value being higher, and because high-grade coals contain less impurities to be got rid of in the scrubbers, etc., and also they contain a less percentage of hydrogen.

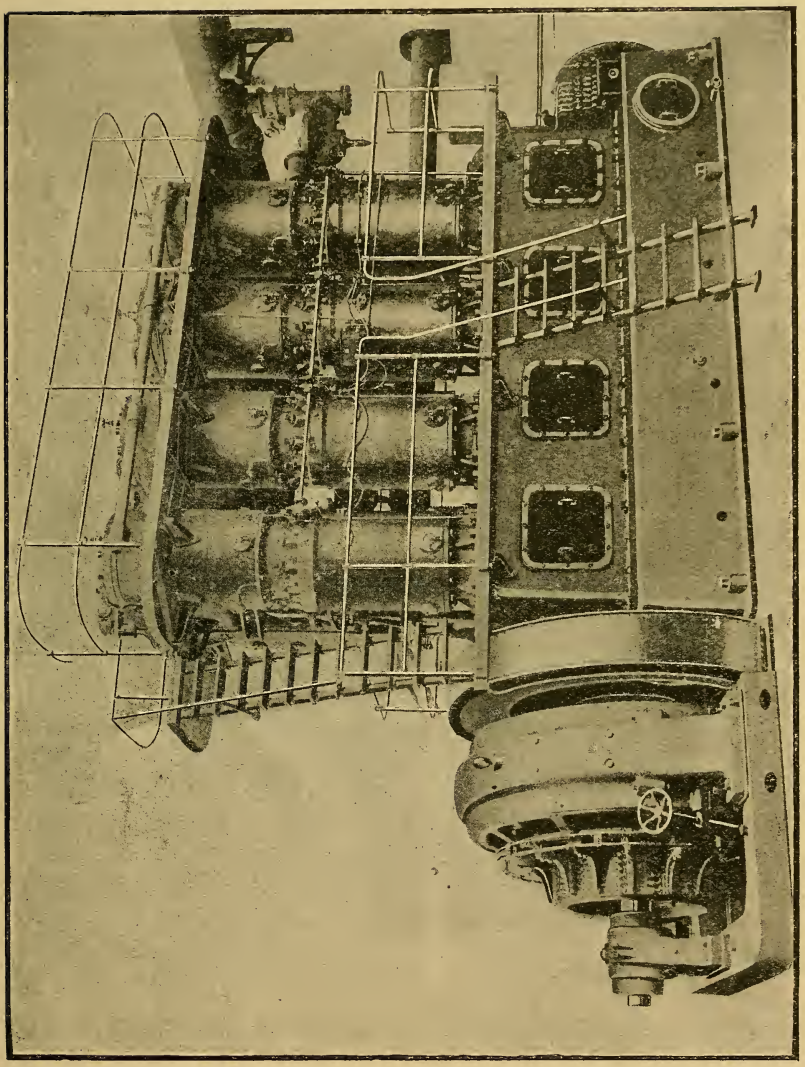


FIG. 113.

TABLE LXXXIII.

Approximate B.H.P. with producer gas.	Number of cylinders.	Number of cranks.	Speed per R.P.M.	Overall dimension of engines and fly-wheel.			Requisite min. height from floor level to crane hook.	Overall dimensions with alternator and exciter.		Depth of foundation on approved sub-soil.	Heaviest lift.	Approximate nett weight engine only.	Generator.	Approximate price of combined set f.o.r. at makers' works.	
				Length.	Width at base.	Height.		Length.	Width.					D.C. generator.	A.C. generator and exciter.
				ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	ft. ins.	tons.	tons.	K.W.	£	£
100	4	2	325	8 4	4 0	11 0	17 6	15 1	5 6	6 0	2·5	9·38	65	1260	1325
150	6	3	325	10 9	4 9	11 0	17 6	17 6	6 0	6 0	3·5	13·4	75	1445	1490
225	4	2	300	10 2	6 0	12 4	19 6	17 6	7 6	8 0	6·75	20·0	155	2068	2100
335	6	3	300	12 9	5 8	12 4	19 6	20 4	7 6	8 0	9·5	28·0	230	2530	2550
460	4	2	200	14 0	7 8	18 4	29 0	24 0	9 6	10 0	11·5	43·7	315	4260	4280
690	6	3	200	18 0	7 8	18 4	29 0	27 0	13 6	10 0	16·0	62·5	475	5560	5560
915	8	4	200	22 0	7 8	18 4	29 0	31 10	14 2	10 0	20·0	79·0	635	7080	7080

NOTE.—It must be particularly noted that the above are only approximate prices, excluding erection, and would require to be modified to suit details of contract payment and conditions and variable prices of material. They may be used, however, for approximate estimating purposes.

The composition of Welsh anthracite and average bituminous coals is as follows :—

TABLE LXXXIV.

Class of coal.	Fixed carbon.	Volatile matter.	Calorific value per pound of combustible B.Th.U.
	per cent.	per cent.	
Anthracite	97 -92·5	3 -7·5	14,600-14,800
Semi-anthracite . . .	92·5-87·5	7·5-12·5	14,700-15,550
Semi-bituminous . . .	87·5-75	12·5-25	15,500-16,000
Bituminous	75 -60	25-40	14,800-15,200
Lignite	under 50	over 50	11,000-13,500

The calorific value of coal should be determined by calorimeter or may be calculated from its analysis. If by the latter method the following formula should be used, viz.—

$$\text{B.Th.U. per lb. of combustible} = 14{,}600\ \text{C} + 62{,}000\left(\text{H} - \frac{\text{O}}{8}\right) + 4000\ \text{S},$$

when C, H, and S represent percentages of carbon, hydrogen, and sulphur per pound of coal respectively.

The impurities contained in the gas derived from one ton of coal of each of the two classes and which have to be removed are approximately—

	Ammonia.	Tar.	Sulphur compound.
	lbs.	lbs.	
Anthracite	1-2	5-10	traces
Bituminous	4-5	10-12	slight to 5%

The sulphate of ammonia recoverable has a commercial value as well as the tar and sulphuric acid—but the recovery plant adds considerably to the capital cost of the power house. This will be dealt with at greater length later. Producers are either of the suction type for small sizes, or of the pressure type for large sizes. In the suction types the gas engine itself provides the draught necessary for the proper combustion of the fuel by the suction stroke of the piston.

The larger pressure producers are provided with blowers which force air, previously heated by passing through an economizer, through the producer.

Details of Gas Producer.—A description of the producer itself, slightly more in detail, may be of use to the designer. The essential parts are the furnace, in the lower part of which the fuel is burnt and forms carbon dioxide. The water vapour made in the vaporizer is broken up on its passage through the fuel, and dissociated into its constituent elements. The mixture of saturated air is forced or drawn in from the underside of the grate. In the upper layers of incandescent fuel the carbon dioxide is converted into carbon monoxide, and the oxygen liberated from the aqueous vapour is utilized to form more CO by combination with the free carbon. The temperature of the furnace gradually rises from the grate-level to the layer at which carbon monoxide begins to be formed, where it reaches a figure of some 1800° Fahr. From this level the temperature gradually diminishes, and the gases leave the producer at a temperature of about 1600° Fahr., and consist of hydrogen and carbon monoxide diluted with the nitrogen from the air and some carbon dioxide which has not been broken up into carbon monoxide.

The following Table, No. LXXXV., prepared by Sankey, gives an average composition when working with anthracite:—

TABLE LXXXV.

		By volume.	By weight.
Combustible gases	Hydrogen	H 14·5	1·2
	Carbon oxide	CO 20·8	23·5
	Methane	CH_4 1·2	0·7
Incombustible gases	Carbon dioxide	CO_2 6·5	11·5
	Nitrogen	N_2 55·5	67·0
	Oxygen	O_2 0·5	0·6

Size of Producers.—The area of cross section of a producer furnace averages from 0·065 to 0·075 square foot per B.H.P. required, and the volumes vary from 0·118 to 0·105 cubic foot per B.H.P.

The firebrick linings of producers require very careful arrangement, since they have a considerable effect on the formation of clinker, on the liability of the clinker to adhere, and on the ease

with which it can be removed. If the interior is difficult to get at, defective joints may arise, which will let in air, produce intense local heat, form clinker, and injure the producer. The arrangement of the hopper has to be such that on the admission of coal there may be no leakage of air.

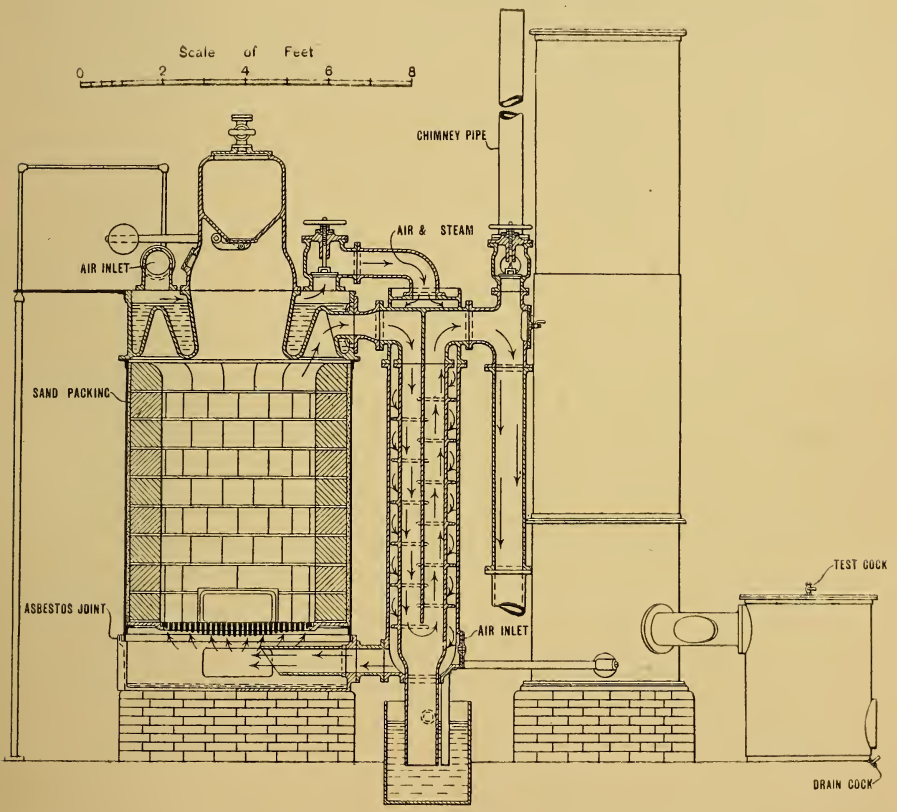


FIG. 114.

The amount of air admitted to the engines is usually 1 to 1½ for producer gas, and 1·9 for town gas.

Fig. 114 is a section through a modern producer, and shows the detailed setting and coal feeding apparatus.

Table No. LXXXVI. gives the details of standard sizes of gas producers.

TABLE LXXXVI.

STANDARD SIZES OF MOND GAS PRODUCERS.

Output.	Gas production per hour.	Gross weight, including coal-handling plant.	Overall dimensions of plant.	
			Length.	Width.
B.H.P.	cub. ft.	tons.	ft. ins.	ft. ins.
100	7,500	22	33 0	32 0
200	15,000	41	51 0	28 6
300	22,500	50	52 6	34 6
400	30,000	59	55 0	33 0
500	37,500	69	55 0	35 0
600	45,000	76	54 6	37 0
800	60,000	106	68 0	39 0
1000	75,000	127	71 0	44 6

The following notes represent the principal claims of the Mond Producer:—

1. Large and effective grate area per producer.

2. The steam blast distributed evenly over the whole grate area, thus giving an excellent and a speedy combustion.

3. The ashes can be withdrawn evenly at all points round the producer by means of the water lute provided at the bottom, and while working at full load.

4. The producer is fitted with sight holes and with sliding doors, enabling the whole of the grate to be visible and accessible to the stoker.

5. The design is specially adapted for running continuously for long periods, with the cheapest qualities of coal. A fair quality of slack will give from 0·8 to 1 B.H.P. hour per pound of fuel.

6. The time required to start a 1000 H.P. plant after a week-end stoppage is only ten minutes.

7. The banking losses of a 1000 H.P. producer represents only $7\frac{1}{2}$ lbs. of fuel per hour.

The gas, after leaving the producer, passes through a dust separator and cooling towers. In these much of the tar and dust is deposited, and the gas temperature is reduced approximately to the temperature of the surrounding atmosphere.

After leaving the towers, the gas passes through a washer, in

which the bulk of the tar is extracted. Thence the gases pass through the sawdust scrubber.

The scrubber requires to be cleaned out and refilled two or three times a year.

One-third of a gallon of water per B.H.P. hour is sufficient for cleaning the gas under normal conditions of working.

The gas consumption per K.W. hour of gas-engine driven electrical generators is generally as follows: —

	Rated load.	Three-quarter load.	Half load.	Quarter load.
	cub. ft.	cub. ft.	cub. ft.	cub. ft.
Blast furnace . . .	140	156	204	314
Coke oven	27	30	39	60
Producer gas . . .	97·2	108	141	217

The following curve, Fig. 115, shows the consumption obtained by a 1500 B.H.P. engine supplied with producer gas.

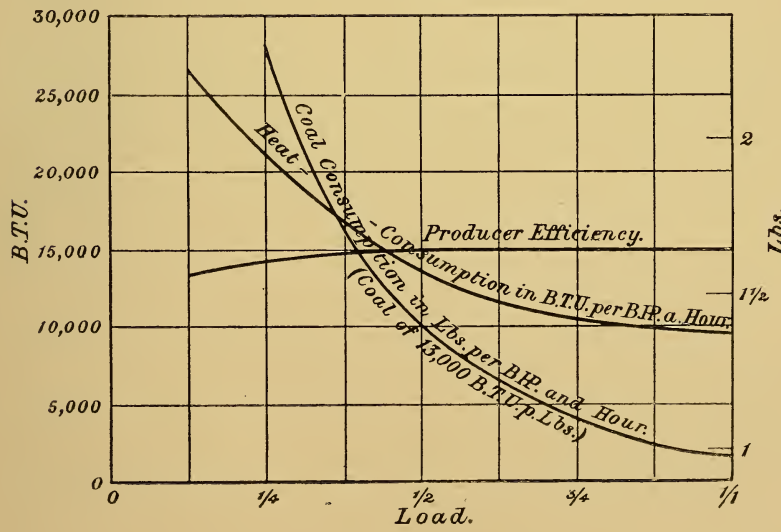


Fig. 115.

The Mond Producer is specially designed to deal with cheap forms of bituminous coal or slack for power gas, and at the same

time to recover the ammonia as a by-product. One of these complete sets is shown in Fig. 116, and a description is taken from a paper by H. A. Humphrey (*Inst. Mech. Engineers*, 1901).

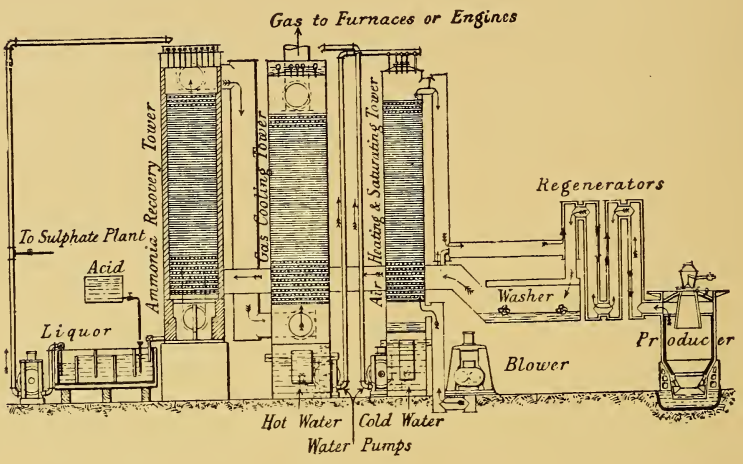


FIG. 116.

The slack is mechanically handled by elevators and creepers, and is deposited in hoppers above the producers. Thence, it is fed in charges of from 8 to 10 cwts. at a time into the producer "bell" where the first heating of the slack occurs. The products of distillation pass downwards into a zone of incandescent fuel before joining the bulk of the gas leaving the producer. This hot zone destroys the tar and converts it into a fixed gas, and also prepares the slack for its descent into the body of the producer, where it is acted upon by an air blast which has been saturated by steam at 85° C. and superheated before coming in contact with the fuel. The quantity of steam introduced is relatively large, amounting to $2\frac{1}{2}$ tons per ton of fuel gasified. This large quantity of steam keeps down the temperature of the producer within such limits as to prevent the formation of clinker or the destruction of the ammonia, and yet allows the fuel to be so thoroughly consumed as to leave only a small residuum of ashes. Half a ton of steam is decomposed for every ton of fuel burnt, yielding thereby free hydrogen amounting to 29 per cent.

by volume of the final gas. The hot gas and remaining steam on leaving the producer first pass through a tubular regenerator in the opposite direction to the incoming blast, which receives some of the heat. The blast is still further heated by passing down the annular space and surrounding the producer body on its way to the grate. The gases after leaving the generator pass through a "washer" which consists of a large rectangular iron chamber with side lutes. Here they meet with a water spray agitated by revolving dashers. This intimate contact of the gases and the water spray reduces the gas temperature to about 90° C. Thence, passing upwards through a lead-lined tower, filled with tiles so as to present a large surface, the producer gas meets a downward flow of acid liquor, circulated by pumps, containing sulphate of ammonia with about 4 per cent. excess of free sulphuric acid. This forms further sulphate of ammonia as described hereinbefore. The gas then freed from its ammonia is led into a gas-cooling tower, where it meets a downward flow of cold water, thus further reducing its temperature, cleaning it of tar, and making it ready for use in the engines.

The producer can be controlled automatically in a simple manner; it will respond at once to any reasonable sudden increase in demand. The speed of the air blower can be controlled by the pressure of the gas in the holder or in the mains, and any fluctation can thus be automatically balanced. The stand-by losses are very small.

The analysis of Mond Gas has been previously given in Table No. LXXIX., p. 241.

The following is an estimate by H. A. Humphrey of a 20,000 H.P. gas-engine plant supplied by Mond Gas Producers.

A gas-driven generator requires 105 cubic feet of Mond gas at 0° C. per K.W. hour; and allowing for auxiliary machinery 125 cubic feet. One ton of coal will yield gas for 1059 K.W. hours.

The cost of production will thus be :—

TABLE LXXXVII.

COST OF PRODUCTION BY 20,000 H.P. MOND PRODUCER GAS PLANT ON AN ANNUAL LOAD FACTOR OF 33⅓ PER CENT.

Capital cost.	£	Revenue cost.	d.
Slack handling, regenerator plant and gas producers .	26,500	Fuel at 8s. per ton . . .	0·217
Acid towers, recovery and sulphate plant	17,100	Oil, waste, and stores . .	0·030
Steam raising plant and sundries	19,000	Labour, attendance, producer plant, gas engines, etc.	0·068
25,000 H.P. gas engines and electrical machinery . .	190,000	Repairs and maintenance, producer plant, gas engines, etc.	0·077
Pipework and cooling towers, buildings and foundations at £1·9	47,000	Capital charges at 6¼ per cent. per annum . . .	0·077
Total . . .	300,100	Total . . .	0·469

Cost per K.W. installed £12·04.

J. R. Bibbins records the commercial results of a thirty-day test of plant at the Richmond Works of the American Locomotive Co. Va. (*American Inst. E. E.*, 1908, Vol. 27).

The plant was running at 312 K.W. (91 per cent. of rated load), and consisted of one horizontal tandem gas engine of the double-acting type, giving two impulses per revolution, operating on producer gas generated by a pair of 9 foot bituminous producers. The results of the test are given in Table No. LXXXVIII.

TABLE LXXXVIII.

	Full.	Three-quarter load.	Half load.
Length of run, hours	223	125	136
Average K.W.	312·3	228·3	159·6
Coal gasified lbs.	115,289	54,143	47,775
Coal gasified per hour	517	433	351
Output in K.W. hours	69,650	28,540	21,710
Lbs. coal per K.W. hours . . .	1·654	1·697	2·20
Average calorific value coal . . .	14,392	14,392	14,392
B.Th.U. per K.W. hour. . . .	23,700	27,280	31,650
Per cent. efficiency	14·35	12·65	10·78

Summarizing the above results, the standby losses of producers may be taken at approximately 1 cwt. of fuel per annum per K.W. installed. Thus, in a 10,000 K.W. power house, the standby losses may be taken as being 500 tons per annum. The auxiliary machinery may generally be taken to require 5 per cent. of the full load output.

The water consumption with non-recovery plants with cooling towers is from 5 to 8 lbs. per K.W. hour, and for recovery plants about 40 lbs. per K.W. hour.

Typical Producer Plant.—Messrs. Andrews and Porter described a producer plant for a large installation in 1909 (*Inst. E. E. England*, Vol. 43), which is typical of an installation on a large scale. Through their courtesy the Figs. 117 and 117A are reproduced.

Coal is taken by an endless conveyor into the overhead bunkers shown in Fig. 117, whence it gravitates through the usual chutes, weighing apparatus, and control valve, to the producer. The ashes are regularly withdrawn through a water lute under the producer every four hours. Air under pressure is admitted at

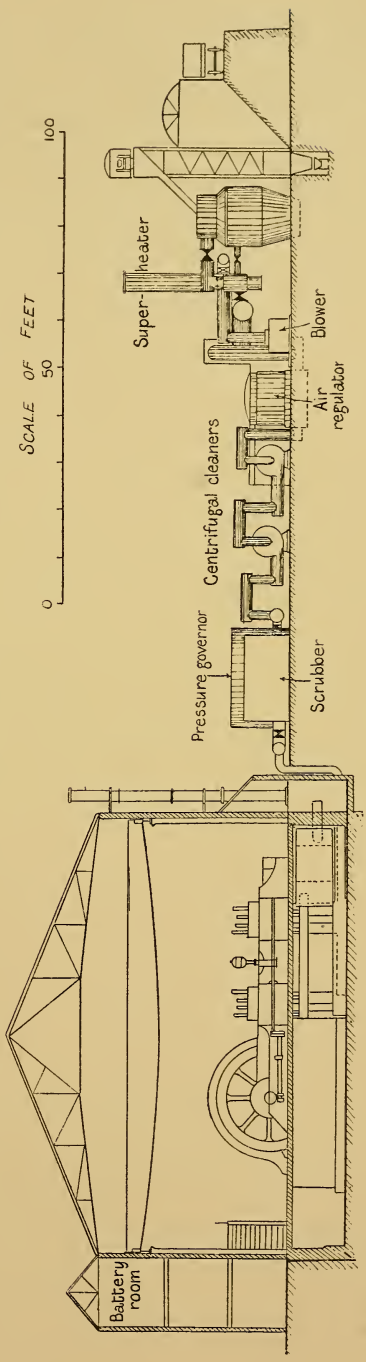


FIG. 117.

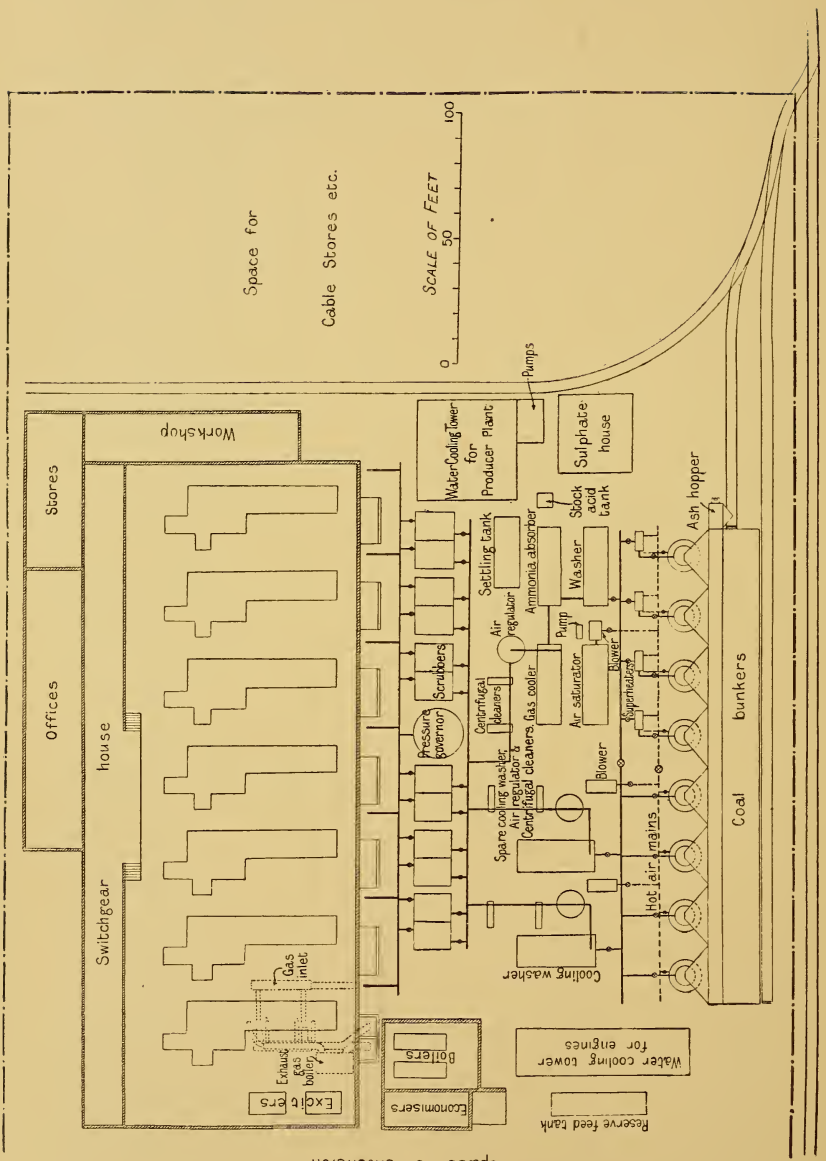

Space for
Cable Stores etc.
SCALE OF FEET
0
50
100
Pumps
Water Cooling Tower for Producer Plant
Sulphate house
Stock acid tank
Ash hopper
Settling Tank
Ammonia absorber
Washer
Air regulator
Pump
Blower
Superheater
Air saturator
Gas cooler
Centrifugal cleaners
Scrubbers
Pressure governor
Spare cooling washer
Air regulator & Centrifugal cleaners
Blower
Cooling washer
Hot air mains
Coal bunkers
Workshop
Stores
Offices
house
Switchgear
Gas inlet
Exhausters
Exhaust gas boiler
Boilers
Economisers
Water cooling tower for engines
Reserve feed tank
Space for extension

FIG. 117A.

the point A shown in Fig. 117, and this air is previously heated by passing through an economizer, also shown in the figure. The hot gases escape through the outlet E at the top of the producer, and pass into the economizer. This consists of a series of vertical pipes surrounded by the steam and air passing on their way to the producer. Thence the gas passes to a mechanical washer, where it is treated with a spray of warm water thrown up by revolving paddle wheels. Thus the dust and soot contained in the gas are removed, and the gas temperature considerably lowered. The warm water is also at the same time further raised in temperature and passed on to the air saturater, in which by heating and saturating the air on its way to the producer the water is cooled for re-use in the washer. The gas next enters the mechanical ammonia-absorber, where it meets a fine spray of a solution of sulphate of ammonia containing a small amount of free sulphuric acid. The acidity of the liquid is kept up by a small trickle of sulphuric acid into the absorber. The sulphate liquid, which is being continually added to by the new sulphate of ammonia formed, trickles out to suitably arranged stock-liquor tanks.

The gas, after passing from the absorber, is next treated in a mechanical gas cooler, where it meets a spray of cold water, and where it gives up the bulk of its tar. Thence it passes to the air regulator, which consists simply of a small gasholder, the height of which regulates the quantity of air supplied by the blowers. It then passes through two centrifugal cleaners arranged in series, which, revolving at a high speed, and supplied with a small quantity of injected water, remove all but slight traces of the remaining tar. These last traces of tar are removed from the gas by passing it through sawdust scrubbers, whence it finally emerges in a thoroughly cool and purified condition into a gasholder or accumulator, which serves to keep a constant pressure in the supply main to the engines.

Where sulphate recovery plant is not required, the gas producer auxiliaries are much simpler. This non-recovery apparatus is shown on the left of Fig. 117A. It will be seen that the gas passes direct into the cooling washer, thence through the air regulator and centrifugal cleaners to the scrubbers and engines.

Sulphate Recovery Plant.—Experience indicates that it is only

worth while to recover sulphate of ammonia in plants having a larger demand than 2000 H.P., and then only on the higher load factors, *i.e.* 25 per cent. or over. Each ton of bituminous coal will produce about 4½ cwt. of sulphate of ammonia. Its adoption must obviously depend on the location of the power house and the market for this by-product. If it is so situated that a good sale of the ammonia can be effected (the average market price at this time is about £11 per ton), then an estimate may be made by the designer whether it will pay to introduce this more costly apparatus or not. Sulphuric acid has to be added, 1 ton of sulphuric being required for each ton of sulphate of ammonia obtained. There is the additional small cost of bags to pack the same. Another point which ought to be considered is whether a compromise may not be economically effected by introducing so many recovery units to deal with the long-hour running sets, and non-recovery units for the peak sets.

It must also be rembered—

(*a*) Considerable extra labour is required in operating recovery plants.

(*b*) The heat units per ton of coal available at the engine are slightly less.

(*c*) There are extra repairs to plant, and the additional cost of handling and packing the sulphate of ammonia.

Fuel and Water Consumption.—The coal consumption per unit generated, exclusive of auxiliaries and all load losses, may be taken at 1 lb., assuming coal with a calorific value of 14,000 B.Th.U. J. R. Bibbins (*Proc. Amer. Inst. E.E.*, Vol. 27) found in a test of a 400-K.W. gas engine generator with producer plant, that the fuel consumption at full load was 600 lbs., of which he

TABLE LXXXIX.

Showing Relation of Coal Thermal Values and Gas Thermal Values.

Coal.	B.Th.U. per cubic foot.	Gas.	B.Th.U. per cubic foot.
Welsh	14,858	Coal . . .	646
Newcastle	14,820	Water . .	295
Derbyshire and Yorkshire	13,860	Producer .	144
Lancashire	13,948	Coke-oven .	603
Scotch	14,164	Blast furnace	91

estimated that one-third was required for auxiliaries and no load losses. Therefore the consumption for all purposes was 1·5 lbs. per K.W. hour. The table on p. 268 gives the relative thermal volumes of coal and gas.

Water is consumed in the vapourizer, scrubbers, and for the cylinder jackets, etc. An amount of about 10 gallons per K.W. hour at 60° Fahr. is required for cooling water, and this amount does not vary materially between half and full loads. This water is, of course, not all wasted, as it may be re-cooled in cooling towers, when an evaporation of 3 per cent. may be taken as a maximum figure in most countries. The make-up water is therefore 0·3 gallon for cooling purposes. The producers require 0·6 gallon per K.W. hour. An increased amount must be allowed for where coke is used as fuel, and water consumption up to 28 gallons per K.W. hour has been recorded in actual practice. This water consumption is therefore not a negligible quantity, and the Author remembers one case of important mines on which he was advising, where water was of great value in the hot season. In this case the water lost was considerably greater than the evaporation from cooling towers for condensers in an equivalent steam plant, and this became so serious a factor in the comparison that steam was adopted. In the above instance the guarantees were 12·2 gallons per K.W. hour for all purposes.

Lubricating Oil Consumption.—The oil consumption of large gas-driven generators is stated by different authorities to vary from 0·2 to 0·37 gallon per 1000 H.P. hours with oil, at an average cost of 1*s.* 6*d.* (35 cents) per gallon, and excluding oil used on auxiliary machinery. Including the latter, a safe estimate gives a figure of 0·45 gallon per 1000 H.P. hours. There are, of course, other stores to be added under the general item "oil, waste, and engine room stores."

Cost of Repairs.—The cost of repairs of gas plants is variously stated. The principal risk arises in fractures of pistons and cylinder liners or cylinder bodies, owing to the large variations of temperature in each cycle. The wear in other moving parts is not appreciably greater than in steam engines, and the regrinding of valves is found, in practice, not to be excessive. The cost of producer repairs and repairs to other auxiliary apparatus is also

found to be small. Probably a figure of £0·5 per annum per K.W. installed, is a fair figure for estimating purposes, excluding depreciation. This is also referred to on p. 246, *ante.*

There can be no question that gas engines on a large and commercial scale are being adopted in Europe and in America with great success. The limiting size of a gas engine cylinder appears to be some 1500 B.H.P., but with twin tandem sets this represents a rated output of 6000 H.P., probably a sufficient size for one gas unit, having regard to the size of producers and other apparatus required.

Capital Cost of Gas Power Houses.—In designing a gas power house it must be remembered that the engines are incapable of more than 10 per cent. overload. The maximum output of a gas engine is reached when the cylinder is full of a mixture of maximum density, analogous to a steam engine taking full-stroke steam. Thus, in comparing the useful outputs from steam and from gas plants, this characteristic of the latter must be kept in mind.

Figures 117 and 117A on pp. 265 and 266 show a typical lay out for a large gas plant with a total plant installed of 10,000 K.W. There are seven units of 1450 K.W. each rated output. The available K.W. demand is, therefore, say 7500, allowing two sets in reserve (or one set in reserve and one under repair, as is reasonable in a commercial station). The capital cost of this plant was estimated as in Table XC.

TABLE XC.

	£
Seven gas engines, generators, air compressers, gas, water, air, and exhaust pipes, and all auxiliaries erected	98,000
Four ammonia recovery producers, erected complete, with superheaters, blowers, cooling and washing towers, centrifugal cleaners, scrubbers, ammonia absorber, and all pipe works	18,490
Duplicate blower, washer, and centrifugal cleaners	3,780
Four non-recovery producers, with scrubbers, etc.	10,340
Steam-raising plant, economizers, feed pumps, etc.	4,850
Water-cooling towers, pumps, and water softener	1,990
Buildings, foundations, etc.	24,275
Overhead travelling crane	1,250
Steel structural work, coal bunkers, coal and ash conveying plant	6,150
Exciters, battery, switch gear, and connection to generators	7,750
Total	176,875

£17·68 per K.W. installed.
£23·57 per available K.W.
5·2 square feet ground space per K.W. installed.
3·9 do. do. available K.W.

The following estimate of a large gas-driven power house is given by Mr. I. V. Robinson :—

TABLE XCI.

	Cost per B.H.P.	Total cost.
	£	£
Nine twin tandem double-acting gas engines, each to develop 2500 B.H.P. at 94 R.P.M.	5·625	112,500
Nine 50-cycle 5000-volt 3-phase alternators direct coupled engines	1·300	26,000
Gas producers, ammonia recovery towers, and exhaust gas heated boilers to supply steam to producers	3·75	75,000
Centrifugal type gas-cleaning plant	0·600	12,000
Engine house, steel skeleton, frame with brick panels 470′ × 80′, fitted with 20-ton crane	1·200	24,000
Foundations for gas engines and engine house 14,000 cubic yards	0·700	14,000
Cooling towers for jacket water, 300,000 gallons per hour	0·100	2,000
Water pumps, air compressor and reservoir for starting engines	0·075	1,500
H.T. switchboard and connecters and motor generators	0·500	10,000
Incidentals, contingencies, etc.	0·550	11,000
Total	14·40	288,000

On an annual load factor of 24 per cent., which may be taken as typical of power houses for general supply, Andrews computes the coal consumption on an output of 21,000,000 units to be as follows :—

	tons.
21,000,000 units delivered at 1 lb.	9,360
17,450 engine hours at 800 lbs.	6,230
85,000 banked producer hours at 50 lbs.	782
	16,372
Contingencies covering variations in value of fuel, heating up cold boilers, leakages, etc.	4,093
Total	20,465

2·18 lbs. fuel per unit generated.
12 per cent. thermo-dynamic efficiency on 24 per cent. annual load factor.

These figures are borne out by several published results from commercial plants giving an average of 13·7 per cent. thermal efficiency in commercial working on average load factors.

The following particulars are of a gas power house which contains three 650 B.H.P. twin tandem engines, or a total of 1950 B.H.P., driving alternators in parallel.

The total capital cost was:—

TABLE XCII.

	£	Per B.H.P. £
Engine-house	3,600	1·846
Engine foundations	1,200	·615
Gas-cleaning plant for five engines	1,250	·641
Water tank and gas holder for five engines	1,450	·743
Three 650 B.H.P. gas engines	9,750	5·000
Electrical equipment, three generators, switchboard, cables, etc.	4,500	2·308
Erection of plant, pipework, starting compressor, travelling crane, etc.	3,400	1·744
Total	25,150	12·897

The following Table, No. XCIII., gives the particulars of running cost, on an annual output of 7,500,000 units, equivalent to a load factor of 65 per cent. The gas was obtained as a by-product from coke ovens, which was formerly wasted. No value has therefore been, in this case, given to the gas.

TABLE XCIII.

	£	Pence per unit.
Lubricating oil	275	·0088
Waste and stores	55	·0017
Water at 5*d.* per 1000 gallons, being the loss through evaporation in cooling towers, 2,064,000 gålls.	43	·0014
Wages	819	·0262
Repairs and maintenance	250	·0080
Interest on capital, 3½ per cent.	880	·0281
Redemption Fund for Renewals—		
Gas engines, 10 per cent.	975	·0312
Generators, etc., 6 per cent.	270	·0086
Buildings, cleaning, plant, gas holder, etc., 3 per cent.	285	·0091
Total	3852	0·1231

Losses in Conversion of Heat Energy of Coal.—An analysis of the average losses in the conversion of heat energy of coal having

a calorific value of 12,500 B.Th.U. by gas producers and gas-driven generators is as follows (at rated load) :—

	B.Th.U.	Per cent.
Loss in producer in auxiliaries	2,500	20
Loss in cooling water for cylinder jackets	2,375	19
Loss in exhaust gases	3,750	30
Loss in engine friction	813	6·5
Loss in generator	62	0·5
Total losses	9,500	76·0
Converted into electrical energy	3,000	24·0

Thus, at rated load and on trial runs the thermal efficiency may be as high as 24 per cent., and in actual service on average commercial load factors the thermal efficiency may be taken at one half of this, or 12 per cent.

A comparison may be made between the thermal efficiencies of steam and gas installations as in Table No. XCIV. One ton of coal with a calorific value of 12,000 B.Th.U. per lb. will produce—

TABLE XCIV.

Gas.	Steam.
140,000 cubic feet of gas with a calorific value of 140 B.Th.U. per cubic foot, or a total of 19,600,000 B.Th.U.	With boiler evaporating an average of 8 lbs. per lb. of coal, a total of 17,920 lbs. of steam.
A modern gas engine requires 9500 B.Th.U. or less per B.H.P. per hour.	A modern turbine requires, say, 13 lbs. of steam per B.H.P. per hour.
Therefore 1 ton of coal will produce 2063 B.H.P. per hour by gas engine.	Therefore 1 ton of coal will produce 1380 B.H.P. per hour by steam turbine.
Ratio gas : steam, 1·5.	Ratio steam : gas, 0·66.

Regulations for Producer Plants.—The following extracts from the Regulations of the National Board of Underwriters will be useful in the installation of producer gas plants.

(a) All pressure systems must be located in a special building approved for the purpose, and at such a distance from other buildings as not to constitute a danger.

(*b*) The smoke and vent pipe shall, where practicable, be carried above the roof of the building in which the apparatus is contained, and shall not pass through floors, roofs, or partitions, and shall end at least 10 feet from any wall.

(*c*) When the plant is not in operation the connection between the producer and scrubber must be closed, and that between the producer and vent pipe opened, so that the products of combustion may be carried into the atmosphere. This must be accompanied by a mechanical arrangement which will prevent one operating without the other.

(*d*) Before undertaking repairs which involve opening the gas passages to the air, the producer fire must be drawn and quenched and all combustible gas blown out of the apparatus through the vent pipe.

(*e*) The opening for admission of fuel shall be provided with some charging device, so that no considerable quantity of air can be admitted while charging the producer.

Combined Gas and Steam Power Houses.—There is a good deal to be said for this combination for general power supply, as by its means a compromise can be obtained in capital cost, and in obtaining an effective running combination, the gas plant taking care of the higher plant load factors, and the steam plant of the peak loads. Such a combination is, of course, more applicable to plants running on the lower annual load factors. Messrs. Andrews & Porter gave estimates for such a combined plant in their paper read before the Inst. of Electrical Engineers (England) in 1909. In this case a plant with an annual load factor of only 10 per cent. was taken, the average price of coal being 8*s.* per ton, there being no credit taken for any ammonia recovery. In the following Table, No. XCV., the estimated running costs were based on the following installations:—

Column A, steam plant, five 1000-K.W. turbo generators.

Column B, gas plant, seven 700-K.W. gas-driven generators.

Column C, combined plant, four 1000-K.W. steam turbo generators and two 700-K.W. gas-driven generators.

Thus the gas plant under these conditions shows an economy of 6 per cent. over the steam plant, and the combined plant 3 per cent.

TABLE XCV.

	A Steam.	B Gas.	C Combined.
	£	£	£
Coal	3,916	2,073	2,781
Oil, waste, and stores . . .	95	297	248
Water	710	100	170
Labour	2,400	2,500	2,745
Repairs	1,250	1,250	1,250
Interest and depreciation at $6\frac{1}{4}$ per cent. per annum . .	4,657·5	5,986·2	5.399·3
Total . . .	13,028·5	12,206·2	12,603·3

The curves shown in Fig. 118 show the effect of the cost of coal upon these various plants and for three annual load factors, viz. 10 per cent., 15 per cent. and 24 per cent. From these curves it will be observed that the higher the price of coal the greater the economy from the combined plant.

Future power houses will probably be constructed along these lines, as the enormous strides made in the development of the gas engine will undoubtedly cause them to be adopted for partial use in power houses.

It has been suggested by Stott and by Andrews that a combined gas plant and

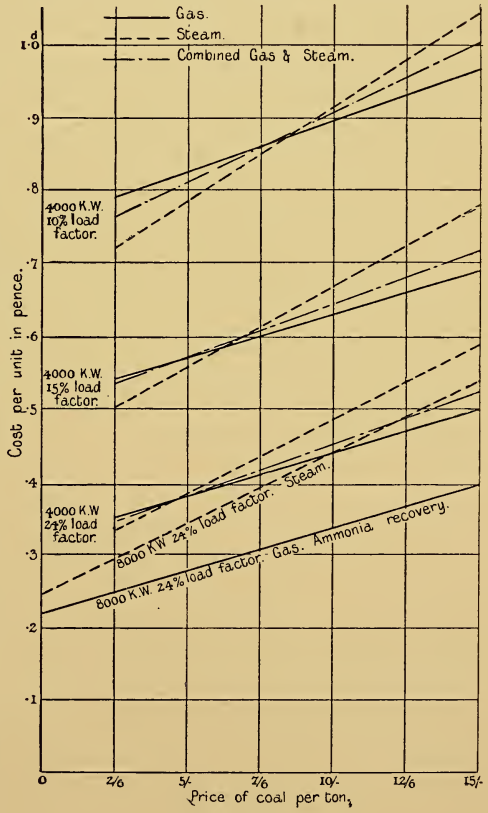


FIG. 118.

steam plant would produce the greatest economy, the steam plant caring for the fluctuating loads and the gas plant working on a 100 per cent. load factor. The relative economy depends on the cost of fuel, load factor on the whole plant, and the market for by-products.

The following description of a small gas power house erected at Swindon, for the Great Western Railway Carriage and Waggon Works, may be of interest. Anthracitic coal producers are used, each being 6 feet 3 inches in height by 3 feet 9 inches diameter, and provided with two scrubbers, each 16 feet high by 3 feet 6 inches diameter, as shown in Fig. 119. The fuel is shovelled direct into the charging hoppers from an elevated platform. There are two vertical gas engines, direct coupled to D.C. generators, each 250–290 B.H.P., at a speed of 225 R.P.M. The consumptions are 0·9 lb. anthracite per B.H.P. hour at full load; 0·97 lb. anthracite per B.H.P. hour at three-quarter load; 1·1 lbs. anthracite per B.H.P. hour at half load.

The thermal efficiencies are as follows:—

Engine and producer, full load .	I.H.P. 22·8	per cent.
„ „ „ .	B.H.P. 19·3	„
Engine only	I.H.P. 30	„
„	B.H.P. 25·5	„

A general view of this plant is shown in Fig. 120.

The following Table, No. XCVI., gives the working cost of a modern shipyard installation:—

TABLE XCVI.

POWER EQUIPMENT OF A MODERN SHIPYARD.

Three 2000-H.P. (Mond) Gas Producers.

Three 250-H.P. gas engines, each direct-coupled to a 140-K.W. D.C. generator, 440-v. compound wound.	One 220-K.W. gas-engine, direct-coupled to D.C. generator, is now in course of erection.
Two 400-H.P. gas engines, each direct-coupled to a 240-K.W. D.C. generator.	Two 260-B.H.P. gas engines, direct-coupled to air compressors.

Fuel used:—Lancashire Special Gas Slacks. Cost, about 10*s.* 6*d.* per ton.

WORKING COSTS.

Week ending.	Total B.T. units.	Power station wages.	Repairs.	Oil.	Stores.	Coal and producer wages.	Total cost.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
Nov. 10, 1909 . .	40,401	·0369	·016	·006	·005	·281	·344
Nov. 17, 1909 . .	41,278	·036	·014	·003	·005	·270	·328
Nov. 24, 1909 . .	44,347	·033	·012	·005	·005	·262	·317
Dec. 1, 1909 . . .	49,905	·032	·012	·002	·005	·24	·291

Average cost per unit for four weeks = ·320*d.*

Standard for Gas Measurement.—The volume of gas measured at any temperature should be reduced to the equivalent at a standard temperature and atmospheric pressure, corrected for the effect of moisture in the gas. The standard recommended is the equivalent volume of the gas when saturated with moisture at normal atmospheric pressure at a temperature of 60° Fahr. To reduce the volume at any other temperature to this standard, the reading should be multiplied by the following factor, viz. :—

$$\frac{459{\cdot}4 + 60}{459{\cdot}4 + T} \times \frac{B - (29{\cdot}92 - V)}{29{\cdot}4}$$

where B = barometer in inches at 32° Fahr.

T = temperature of gas at meter in degrees Fahr.

V = vacuum in inches Hg corresponding to temperature T.

Tests.—The following form for internal combustion engine testing is recommended by a committee of the American Society of Mechanical Engineers :—

1. Type and class of engine.
2. Class of fuel used—
   - (*a*) Specific gravity.
   - (*b*) Burning point degrees Fahr.
   - (*c*) Flash power „ „
3. Dimensions of engine—
   - (*a*) Class of cylinder (working or for compressing charge).
   - (*b*) Single or double acting.
   - (*c*) Cylinder dimensions.
   - (*d*) Average compression clearance per cent.
   - (*e*) Horse-power constant for 1 pound mean effective pressure and 1 revolution per minute.

Total Quantities.

4. Duration of test.
5. Gas or oil used (cubic feet or lbs.).
6. Cooling water supplied to jackets, etc., gallons.
7. Calorific value of fuel in B.Th.U. determined by calorimeter test.

Pressures and Temperatures.

8. Pressure at meter (if gas engine) in inches of water.
9. Barometer—
   (*a*) Actual.
   (*b*) Corrected to 32° Fahr.
10. Temperature of cooling water.
   (*a*) Inlet degrees Fahr.
   (*b*) Outlet „ „
   (*c*) Humidity.
11. Temperature of gas degrees Fahr. at meter (if gas engine).
12. Temperature of atmosphere degrees Fahr.
   (*a*) Dry bulb thermometer.
   (*b*) Wet „ „
13. Temperature of exhaust gases degrees Fahr.

Heat Measurement.

14. Heat units consumed per hour (pounds of oil or cubic feet of gas multiplied by the total heat of combustion) B.Th.U.
15. Heat rejected in cooling water per hour B.Th.U.

Speed, etc.

16. Revolutions per minute.
17. Average number of explosions per minute.

Indicator Diagrams.

18. Pressure in pounds per square inch above atmosphere.
   (*a*) Maximum pressure (in each cylinder).
   (*b*) Pressure just before ignition.
   (*c*) Pressure at end of expansion.
   (*d*) Exhaust pressure.
   (*e*) Mean effective pressure.

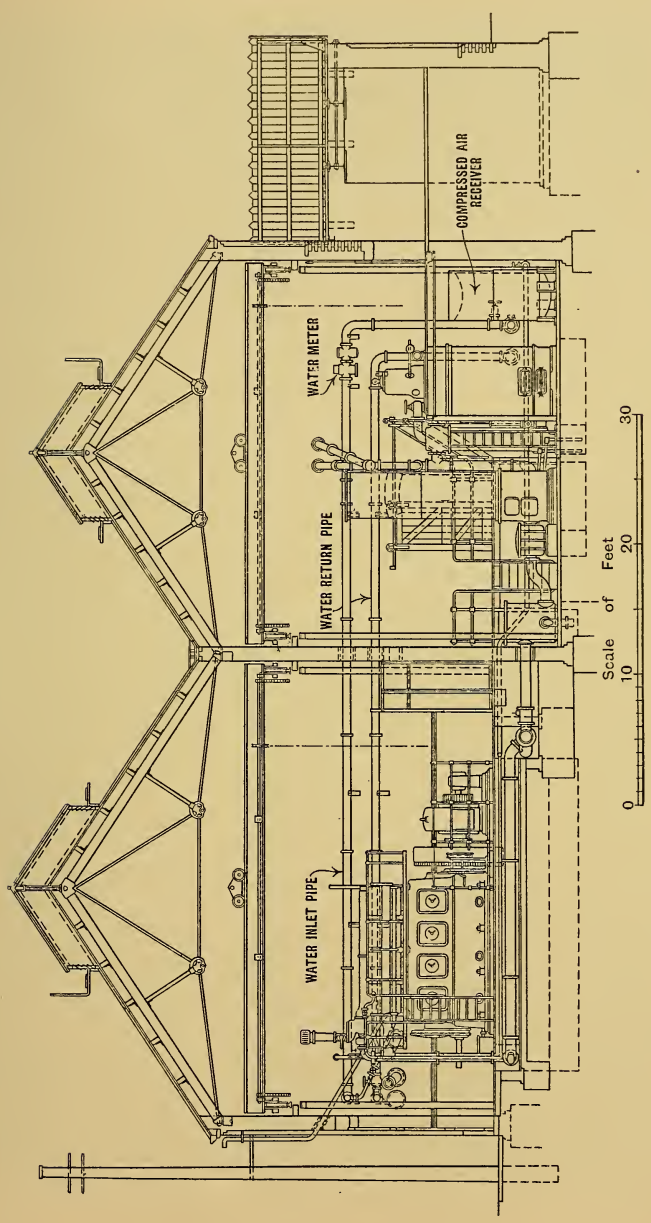

COMPRESSED AIR RECEIVER
WATER METER
WATER RETURN PIPE
WATER INLET PIPE
Scale of Feet
0
10
20
30

FIG. 119.

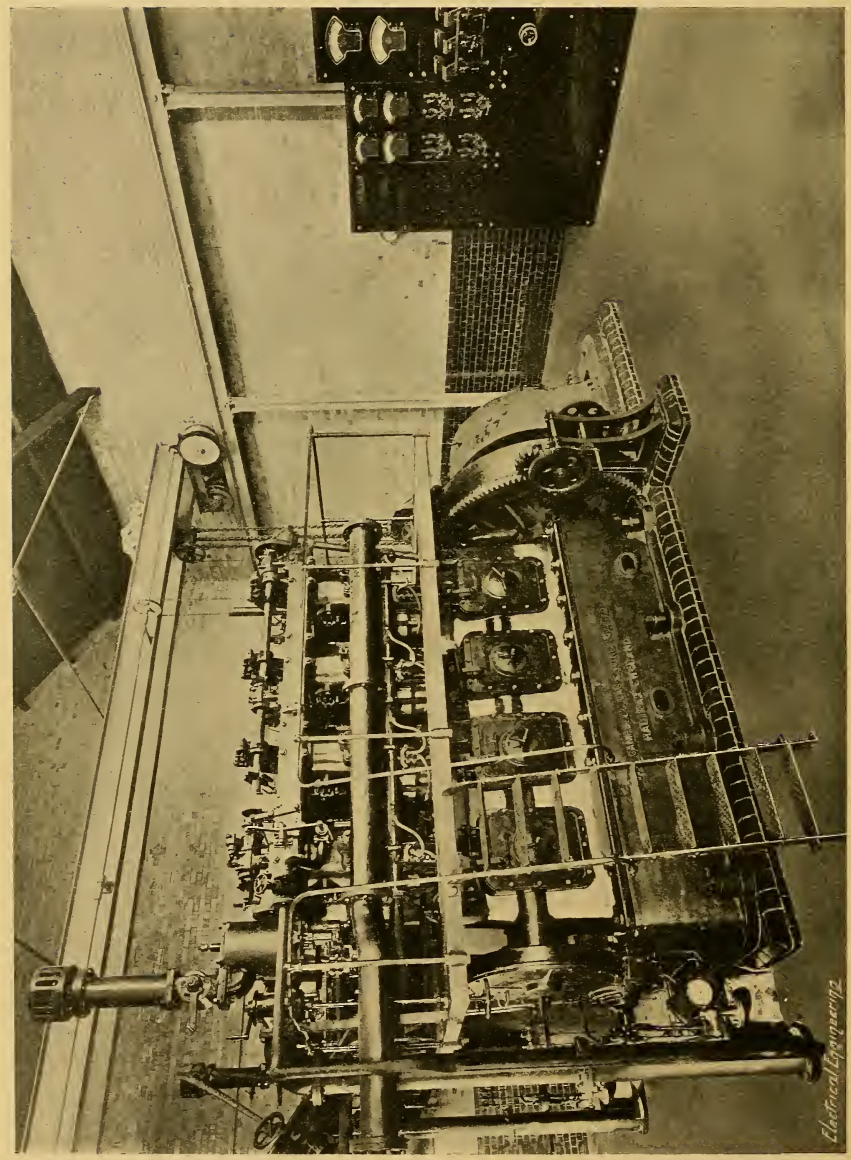


FIG. 120.

Power.

19. Indicated Horse-power (in each cylinder).
20. Brake Horse-power.
21. Friction H.P. from friction diagrams.
22. Percentage of I.H.P. lost in friction.

Standard Efficiency.

23. Heat units consumed by the engine per hour.
    (*a*) Per I.H.P.
    (*b*) Per B.H.P.
24. Pounds of oil or cubic feet of gas consumed per hour.
    (*a*) Per I.H.P.
    (*b*) Per B.H.P.

Oil Engines.—For small power houses and for light load plants in larger installations, a very great economy can be gained by the adoption of oil engines. The best known is the Diesel engine, which is shown in Fig. 121.

The principle of the Diesel engine is the adoption of a high pressure at the beginning of the working stroke and the automatic ignition of the charge by the heat of compression. The working cycle is as follows :—

(*a*) The piston moves downwards, and air at atmospheric pressure and temperature is drawn into the cylinder through a tube provided with a series of narrow slits to serve as a rough filter and silencer.

(*b*) The piston moves upwards, and the air is compressed to about 450 to 500 lbs. per square inch, corresponding to a temperature of 900° to 1000° Fahr., which is far above the flash-point of the oil fuel.

(*c*) Oil fuel is injected into the cylinder by means of compressed air 1° or 2° before the completion of the compression stroke at a constant pressure of 750 or 800 lbs. per square inch, depending on the nature of the oil fuel used. On the next down stroke and during the first part of the stroke the combustion is carried on at practically constant pressure for a period determined by the amount of oil fuel sprayed in, and for the remainder of the stroke the products of combustion do work by expansion.

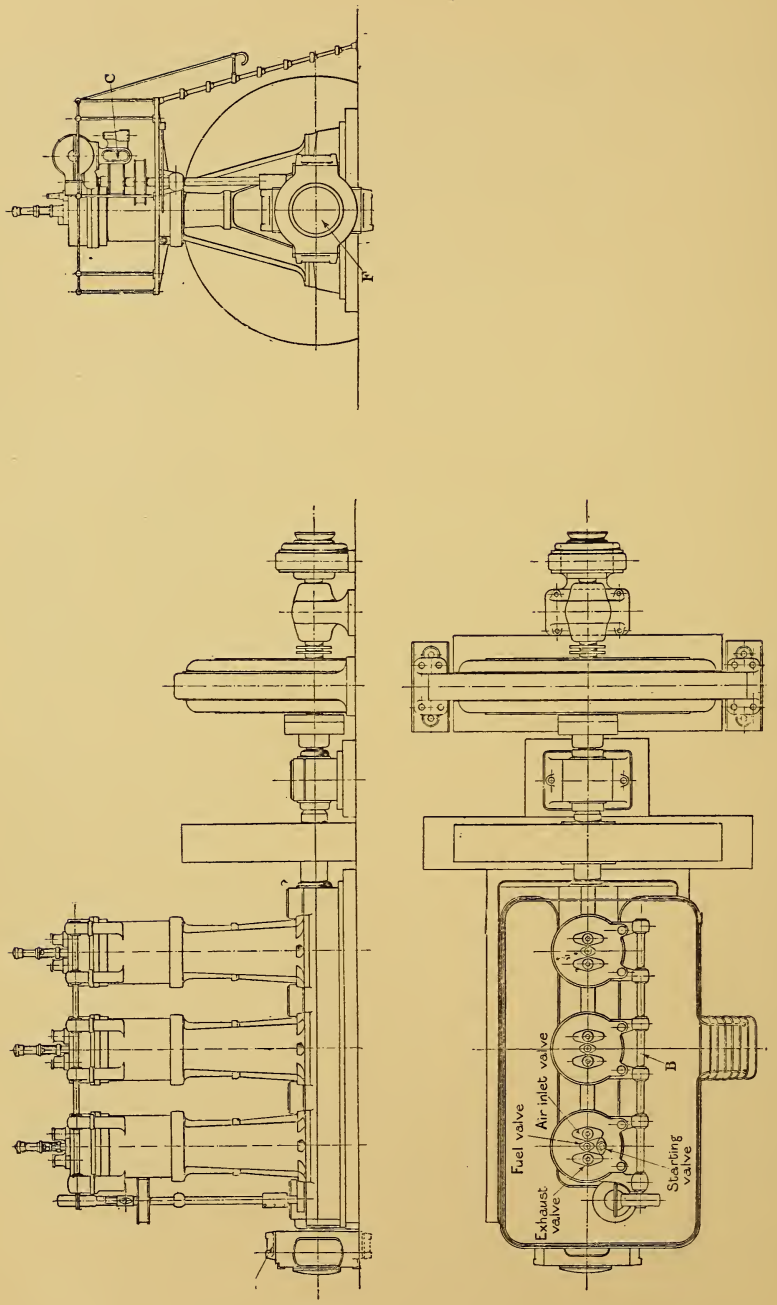

C
F
Fuel valve
Air inlet valve
Exhaust valve
Starting valve
B

FIG. 121.

(*d*) The piston on the next upward stroke drives out the waste gases, which are exhausted to atmosphere, the exhaust pressure at the cylinder being about 40 lbs. per square inch.

Diesel engines are made on the two-cycle principle and also on the double-acting principle for larger units giving one, two, or four working strokes per revolution. In the two-cycle method scavenging the cylinders is accomplished by blowing in fresh air at a pressure of 5 lbs. near the end of the third stroke, thus clearing out the exhaust gases and filling the cylinder with a new charge.

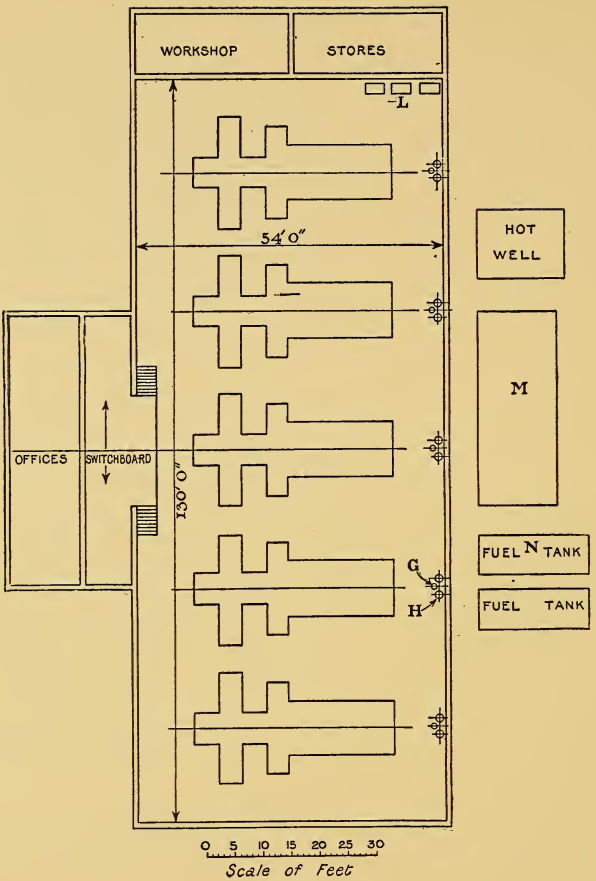
Fig. 121 shows a 3-cylinder single acting 4-cycle engine, and Fig. 122 a general arrangement of a complete plant comprising five 400-K.W. sets. Each cylinder is provided with three valves, viz. exhaust, air inlet, and fuel inlet respectively. One cylinder has a starting valve in addition. These are all operated by springs attached to the valves and cams attached to the shaft B running at half the speed of the engine shaft. The fuel pump is shown at C, the plunger of which is driven directly from the vertical shaft G ; F shows the 3-stage air compressor which compresses the air respectively to 75, 400, and 750 lbs., the air being cooled after each stage by passing it through water-cooled chambers. The compressed air is stored at G, and injects the fuel into the cylinder against the high pressure in it.

H represents the air starting reservoir, for starting the engine, and is connected by an overflow valve with the air blast reservoir.

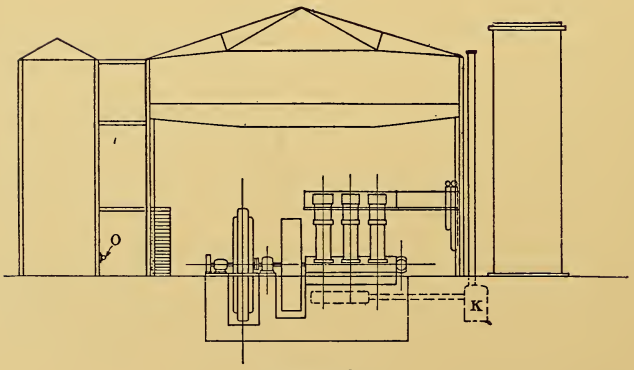
K is the exhaust silencing chamber, L being the water circulating pump for cooling the cylinder and air-pump jackets.

N is the fuel storage tank, and O the service pump for raising the oil fuel from the tank N to the overhead service tanks, from which it is led to the fuel pump by gravity. The engine is started as an air engine by compressed air stored in the air starting reservoir H during a previous run, the pressure being maintained at about 800 lbs.

Crude petroleum contains about 18,500 B.Th.U. per lb., and the following thermodynamic efficiency is claimed at full load.



Plan.



Cross-section.

FIG. 122.

TABLE XCVII. (PFEIFFER).

	Per cent.
Calorific value of fuel	100
Loss in exhaust, cooling, and radiation	55
I.H.P.	45
Loss—engine friction and air pump	11
B.H.P.	34
Generator loss at 91% efficiency	3
Efficiency of oil engine generator	31

These engines are not, however, dependent on crude petroleum only, as for instance the by-product in the shape of oil tar, which is given off by the gas enriching carburetted water-gas plants (used in so many gasworks), is a good oil engine fuel, having a calorific value of about 16,500 B.Th.U. per lb.

The following Table, No. XCVIII., sets out the guarantees for a 600-B.H.P. set supplied with petroleum residue having a calorific value of 18,500 B.Th.U. :—

TABLE XCVIII.

Engine load.	Fuel consumption in lbs. per hour.		Fuel cost in pence.		Efficiency of generator per cent.
	B.H.P.	K.W.	B.H.P.	K.W.H.	
12·5% overload	0·40	0·58	0·080	0·112	93
Full load	0·40	0·58	0·080	0·112	93
Three-quarter load	0·42	0·61	0·084	0·122	92·5
Half load	0·47	0·69	0·098	0·132	92
Quarter load	0·66	1·01	0·132	0·202	88

The United States of America and Russia are the two principal petroleum producing countries, though it is also obtained, in smaller quantities, from Canada, Galicia and the Far East. The following Table, No. XCIX., gives the average figures for American and Russian crude oils and residuals :—

TABLE XCIX.

Fuel.	Sp. gr.	Flash point, deg. Fahr.	B.Th.U. per lb. fuel.
Beaumont crude	0·924	180	19,060
California	0·966	230	18,667
Pennsylvania	0·886	—	19,224
Wyoming	0·996	—	19,668
Residual, Virginia	0·860	—	19,200
do. Russian	0·884	—	19,926
Gas oil tar	—	—	16,500

There are now several public installations of Diesel oil engines in Great Britain, in small towns mainly. The following are among those using Diesel plants, and the figures given in Table No. C. are taken from published returns.

TABLE C.

Undertaking.	System: direct, alternating ~	Diesel plant installed K.W.	Annual load factor per cent.	Units generated.	Average cost of fuel per ton.	Lbs. of fuel per K.W.H.	Works costs per unit generated.					
							Fuel.	Oils.	Stores.	Wages.	Repairs.	Total.
							d.	*d.*	*d.*	*d.*	*d.*	*d.*
Daimler Co.	—	436	46	1,887,200	53/4	0·62	0·178	0·019	0·014	0·064	0·023	0·298
Fareham .	—	200	14	143,545	49/0	0·92	0·320	0·021	0·026	0·435	0·023	0·825
Leatherhead	—	160	13·5	—	—	—	0·226	0·025		0·289	0·038	0·578
Lewes . .	—	120	15	—	—	—	0·21	0·04		0·15	0·08	0·48
Letchworth	—	135	27·2	95,169	43/6	0·65	0·153	0·027	0·015	0·160	—	0·355
Wakefield Light Railways . .	~	400	30·6	743,658	57/6	0·76	0·160	0·015		0·162	0·057	0·394

Pfeiffer quotes the following estimate of the cost of installing a 2000-K.W. plant consisting of five 400-K.W. sets.

TABLE CI.

	£
Five vertical 4-stroke engines coupled to 400-K.W. generators, complete with all necessary pumps, air vessels, etc., pipework, auxiliary pumps, cooling tower, switchboard, cabling and crane. Per K.W. £19·5	39,000
Steel frame building, brick lined, with all foundations, oil storage, tanks, etc. Per K.W. £5·5	11,000
£25 per K.W. Total	50,000

These engines are quite adaptable for driving alternators in parallel, as a speed variation of $\frac{1}{250}$ to $\frac{1}{300}$ can be obtained with only a moderately heavy flywheel.

The makers guarantee 1 B.H.P. hour on 0·6 lb. of crude petroleum.

The following Table, No. CII., shows the Standard sizes of 3-cyclinder engines :—

TABLE CII.

Rated output B.H.P.	R.P.M.	Length.	Width.	Height.
		ft.	ft.	ft.
120	200	16·0	8·833	8·333
150	190	16·416	9·166	10·0
200	180	18·333	9·833	10·5
240	180	20·0	10·5	12·0
250	170	21·0	10·5	12·0
300	160	22·416	11·166	13·0
400	155	23·5	11·833	14·0
450	155	25·0	12·166	14·5
500	150	25·0	12·5	15·75

Table No. CIII. gives the similar figures for the 4-cylinder types, which have a cyclic irregularity not exceeding $\frac{1}{250}$.

TABLE CIII.

Rated output. B.H.P.	R.P.M.	Length.	Width.	Height.
		ft.	ft.	ft.
320	180	24·0	10·5	12·0
400	175	26·0	11·2	13·0
700	150	33·0	14·0	15·5
800	140	42·0	16·0	16·5

The engines include hand-barring gear, outer crank shaft bearing, access platform and stairs, compressed air tanks, pressure gauge and connecting pipework to engine, fuel filter tank, exhaust silencer (one for 3-cylinder and two for 4-cylinder engines), indicator cocks and reducing gear, fuel reservoir, cooling water pump and tank, and pipe work for fuel, exhaust, and connections to cooling tower. In working an oil plant in towns where compliance with smoke regulations must be made, care must be taken

always to work the oil engines above $\frac{1}{5}$-rated load, otherwise smoke will be emitted from the exhaust due to the imperfect combustion of the fuel.

Fig. 123 shows a section through a 2-cylinder 250-H.P. Diesel engine, made by the Augsberg Engine Works. This engine runs at 155 R.P.M., and will develop 300 H.P. on overload. The stroke

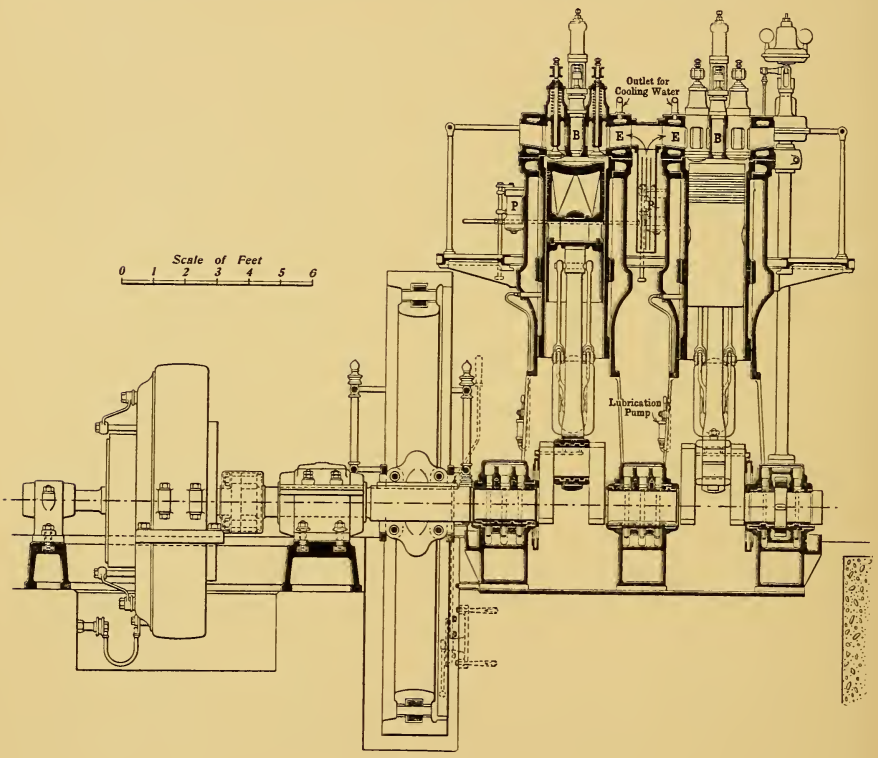


Fig. 123.

is 29 inches, and the cylinder diameter $19\frac{3}{4}$ inches. There are two fly-wheels, one 12 feet 2 inches diameter, weighing 7 tons, and the other 13 feet 9 inches diameter, weighing 15 tons. The variation of angular velocity does not exceed $\frac{1}{140}$.

Fig. 124 shows a cross section of the same engine. There are four valves on the cylinder, (1) the starting valve V, to admit the compressed air; (2) the suction valve E, to admit the air at

atmospheric pressure (see Fig. 123); (3) the full valve B, to admit the liquid fuel; and (4) the exhaust valve. The valves are closed by springs and opened by levers, actuated by the cams S, worked from the rocking shaft H. The shaft H is driven from the crank shaft by two worm wheels and a vertical shaft.

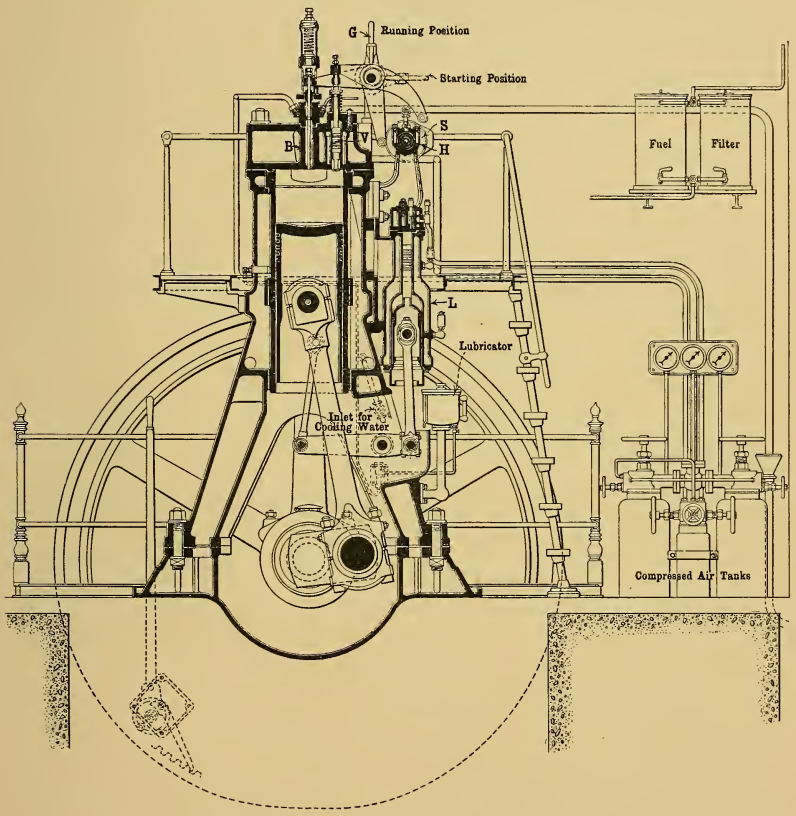


Fig. 124.

The fuel used is paraffin oil, obtained as a waste product from the manufacture of paraffin by the distillation of tar from bituminous coal. The flash point is 212° C., and the calorific value about 17,000 B.Th.U. per pound. Very little residue is found in the cylinders. The actual fuel consumption per B.H.P. hour is as follows :—

Full load . . .	175 grammes . . .	0·386 lb.
¾ „ . . .	184 „ . . .	0·405 „
½ „ . . .	212 „ . . .	0·466 „
⅓ „ . . .	247 „ . . .	0·544 „

The cooling water consumption in this case is 2·2 gallons per H.P. hour.

A reservoir for the fuel oil is supplied, away from the engine room, having a capacity of 12 cubic metres (15·69 cubic yards), with two running reservoirs in the engine room, each of 2 cubic metres (2·62 cubic yards), pumped through filters from the main tank.

A 350-H.P. paraffin engine made by Thorneycrofts, London, with a speed of 560 R.P.M., required 0·328 kilo (0·073 lb.) per B.H.P. hour, 0·017 kilo (0·0374 lb.) of lubricating oil, and 0·063 kilo (0·138 lb.) water per B.H.P. hour, with a mean inlet temperature of 59° Fahr. and an outlet temperature of 95° Fahr.

The following table (No. CIV.) gives the result of an official test of a Diesel engine (with fuel at 18,000 B.Th.U. per lb.):—

TABLE CIV.

Approximate load.	¼	½	¾	1
I.H.P in diagram	114·55	145·34	200·40	222·05
B.H.P.	40·10	70·89	125·95	147·60
Mech. efficiency	43%	55·6%	69%	74·1%
Fuel, oil per hour lbs. . . .	28·65	38·57	57·3	71·41
„ per B.H.P. per hour .	10·715	0·545	0·454	0·484
Thermal efficiency B.H.P. .	18·85%	23·44%	27·33%	28·95%

The results of a test on a 225 H.P. direct coupled set made at Kimberley, Wis. U.S.A., are given in Table No. CV.

In the oil engine, the economy depends on a correct proportionment of the vaporized oil with the air admitted, and a uniform compression of the mixture. The permissible range of this proportion is very small for any oil of given thermal value. If too much oil vapour is admitted, then there will be too little oxygen in the mixture to support complete combustion, with the result that unburned gases will be exhausted, and carbon deposited in

the cylinders. On the other hand, if there be too little oil vapour and an excess of air, then the resultant mixture will cease to be inflammable.

TABLE CV.

B.H.P.	68·15	133·7	194·9	249·7	263·8
K.W.	40·7	84·8	127·3	167·7	177·2
Fuel, oil lbs. per B.H.P. hour	0·776	0·493	0·469	0·464	0·516
Fuel, oil lbs. per K.W. hour	1·29	0·778	0·713	0·69	0·77
Jacket water galls. per hour	2033·5	2528·3	3324·0	3894·5	5306·0
Jacket water galls. per B.H.P. hour . . .	29·5	18·9	17·1	15·6	20·1
Average temp. Fahr. inlet water	34·0	34·0	34·0	38·8	40·0
Average temp. Fahr. outlet water	126·6	135·5	137·9	180·0	170·0
B.Th.U. per B.H.P. hour	15,103	9594	9127	9029	10,041
Thermal efficiency of engine	16·8	26·4	27·8	28·1	25·3

The amount of water circulated round the cylinders is at the rate of 4 gallons per B.H.P. hour, with an outlet temperature not exceeding 120° Fahr.

The make-up water may be calculated at $2\frac{1}{2}$ per cent. of the total circulated.

The lubricating oil required does not exceed 4 grammes per unit generated, or approximately 1000 units generated for each gallon used.

The Author has had to make several investigations into the economics of small supply undertakings driven by steam sets where the annual load factor is poor, being under 16 per cent. In such cases he has found that the addition of a Diesel set to care for the light loads effects a relatively great economy, and greatly reduces the losses due to banking boilers, heating up steam ranges, and running steam sets at light loads with their resultant increase of steam and fuel per unit delivered to switchboard. For isolated plants, where power cannot be purchased at a commensurate price per unit, and as an auxiliary in power houses similarly situated as those mentioned above, the Diesel engine is to be highly recommended.

The by-products from gasworks can be used as fuel in Diesel engines. These are gas oil tar and gas tar oil. The former is a by-product from the manufacture of carburetted water gas plant, used in gasworks to enrich the town gas. The latter is a by-product from the distillation of the former.

A general calorific value of 16,500 B.Th.U. per lb. fuel may be counted upon. In some cases this fuel is enriched by a 10 per cent. addition of crude petroleum.

The engines are built, when so specified, to work either on petroleum or on gas oil tar.

At Halle there are two 1600-H.P. Diesel sets of the horizontal double-acting, four-stroke type. The design is twin tandem, and the engines are of massive construction. Even larger sets are now under construction.

Utilization of Waste Heat. — Manufacturers have at last awakened to the enormous waste which has gone on for years in the blast furnaces for the production of iron and steel and also in coking ovens. Utilization of these waste products has been made in Europe and America. Not the least notable among them is that of the Power Supply Companies, supplying the vast industrial district of the North-East Coast of England. Some of the waste-heat power houses in that district supplying 3-phase energy are given in Table No. CVI.

TABLE CVI.

Location of power house.	H.P. utilized.	Pressure.	Waste heat supplied from
Weardale	6650	3000	Coke ovens
Blaydon	3000	6000	Coke ovens
Bankford	3300	3000	Coke ovens
Newport	4000	3000	Exhaust steam
Tees Bridge	1300	3000	Exhaust steam

In this district an enormous amount of coke is produced annually, the waste gases from which are estimated to produce 250,000 H.P. continuously if used in gas engines, or 150,000 H.P. continuously if used under boilers. The blast-furnace gases are of less importance, but these again are estimated to produce over 50,000 H.P. continuously. It is not always commercially practicable to

utilize these waste gases, having regard to the necessary capital expenditure and the resultant cost of production per unit when compared with the cost of production from an equivalent high-pressure steam-turbine power house, and the designer must work out the relative economies in each particular case.

In America natural gas is transmitted under a pressure of 80 lbs. per square inch for long distances. This gas, however, has a calorific value of approximately 900 B.Th.U. as against the average value of 525 B.Th.U. for coke oven gas. It is found, therefore, to

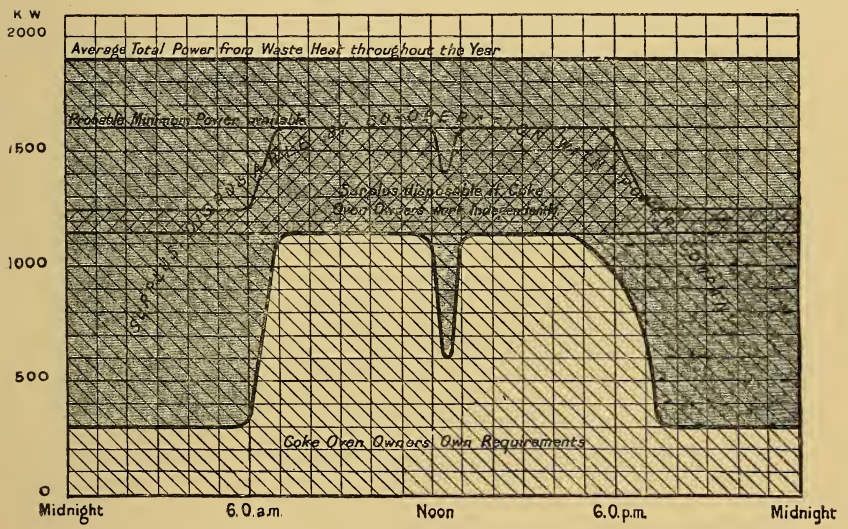


FIG. 125.

be cheaper to utilize the coke-oven gas at a point near to the coke ovens, rather than to transmit the gas to a central point through an expensive pipe line and by means of expensive compressing machinery. In other words, local ultilization and electrical transmission of energy are cheaper than piping and transmission of the gas with distant utilization. In a paper read by Mr. C. H. Merz, before the Iron and Steel Institute, England, in 1908, he showed in Fig. 125 the estimated daily output and load curve of waste heat at the important works of Messrs. Pease & Partners, Crook, Co. Durham. Here a co-operative agreement between the

Power Company and the coke-oven owners was entered into by which the waste heat is transformed into electrical energy and the owners of the coke ovens are given back what power they may require, the surplus (representing an enormous output) being "pumped" into the high-tension transmission mains for utilization throughout the province. If manufacturers produce pig iron only, the Power Company is a useful outlet for the waste products. If, however, the manufacturers also make steel with accompanying rolling mills, then, as in Germany and America, the waste heat can be utilized in the steel works for the blowers and for the requisite local power plant.

Fig. 126 shows views of the coke-oven waste heat power house at Weardale. This contains four specially arranged gas-heated water-tube boilers and four turbo alternators, aggregating 5000 K.W. with complete equipment of condensers and cooling towers. The floor space occupied by the power house is 5·2 square feet per K.W. with cooling towers and 3·6 square feet per K.W. without cooling towers, the cooling towers in this instance requiring 1·6 square feet per K.W. installed.

Another case is shown in Figs. 127 and 127A, which represent an exhaust steam power house. Here the exhaust from the blowing engines is taken through a superheater to the power house, and led to exhaust steam turbines of some 3000 K.W. output in all. The circulating water for this power house is obtained from the neighbouring River Tees, and thus a good vacuum is possible. As has been shown previously, this is an important matter with exhaust steam turbines, whose steam consumption at 26 inches vacuum is half as much again as at a 29 inch vacuum.

As the engineer has to utilize the forces of nature at the lowest cost compatible with good and enduring work, so has he to utilize the natural riches of the earth in the most efficient manner possible. The appalling waste of heat which took place during the nineteenth century has at last been realized, and it is only due to the advances in electrical transmission, as well as the development of the gas engine and steam turbine, that such waste is now being avoided and a greater use made of the stored energy in coal, of which even the present generation is still so prodigal.

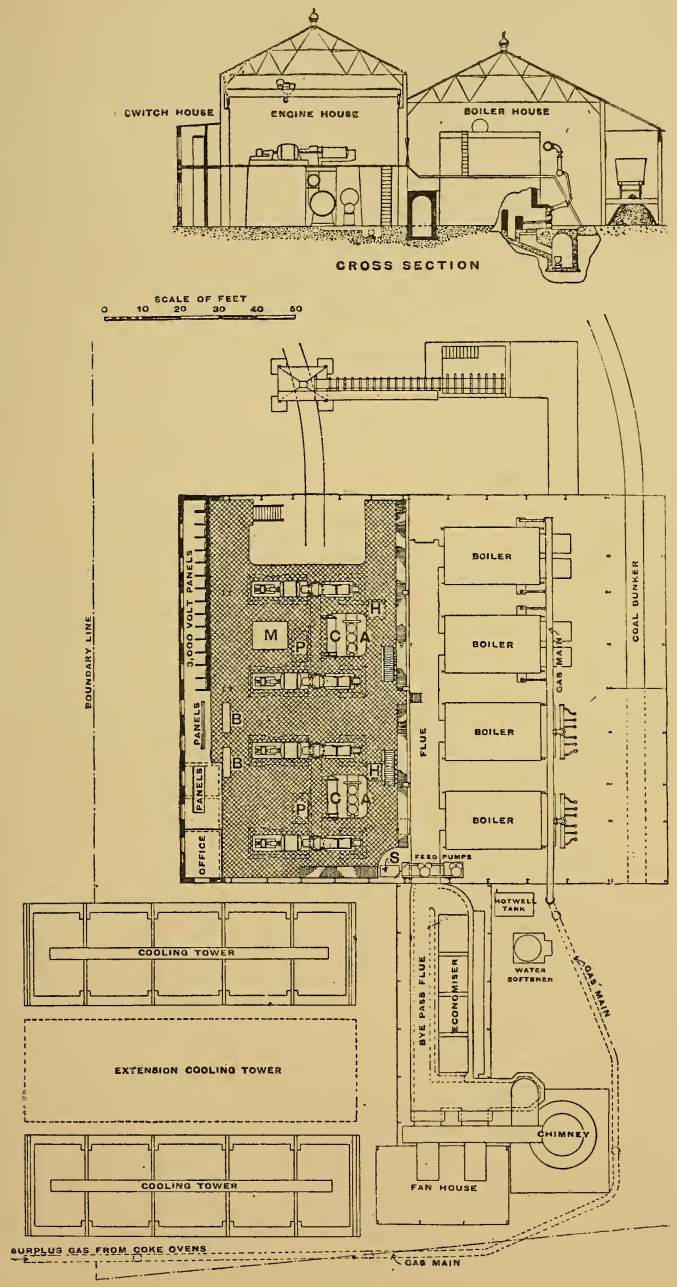

SWITCH HOUSE
ENGINE HOUSE
BOILER HOUSE
CROSS SECTION
SCALE OF FEET
0 10 20 30 40 50
BOUNDARY LINE
3300 VOLT PANELS
PANELS
PANELS
OFFICE
M
P
C
A
H
B
FLUE
BOILER
BOILER
BOILER
BOILER
GAS MAIN
COAL BUNKER
FEED PUMPS
HOTWELL TANK
WATER SOFTENER
COOLING TOWER
EXTENSION COOLING TOWER
COOLING TOWER
BYE PASS FLUE
ECONOMISER
CHIMNEY
FAN HOUSE
SURPLUS GAS FROM COKE OVENS
GAS MAIN

FIG. 126.

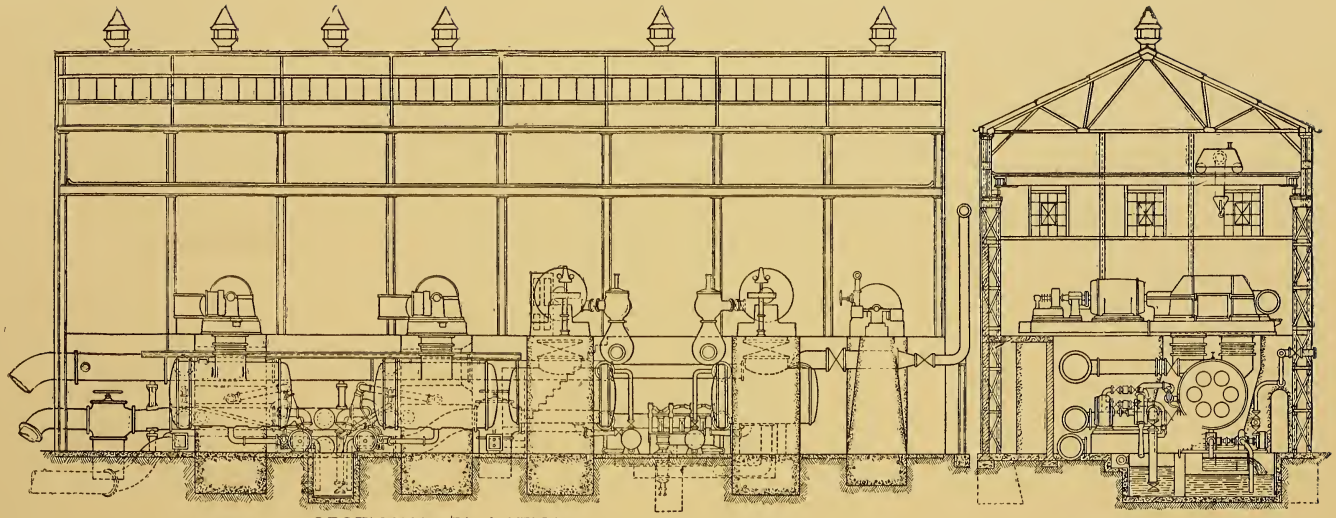


Fig. 127.

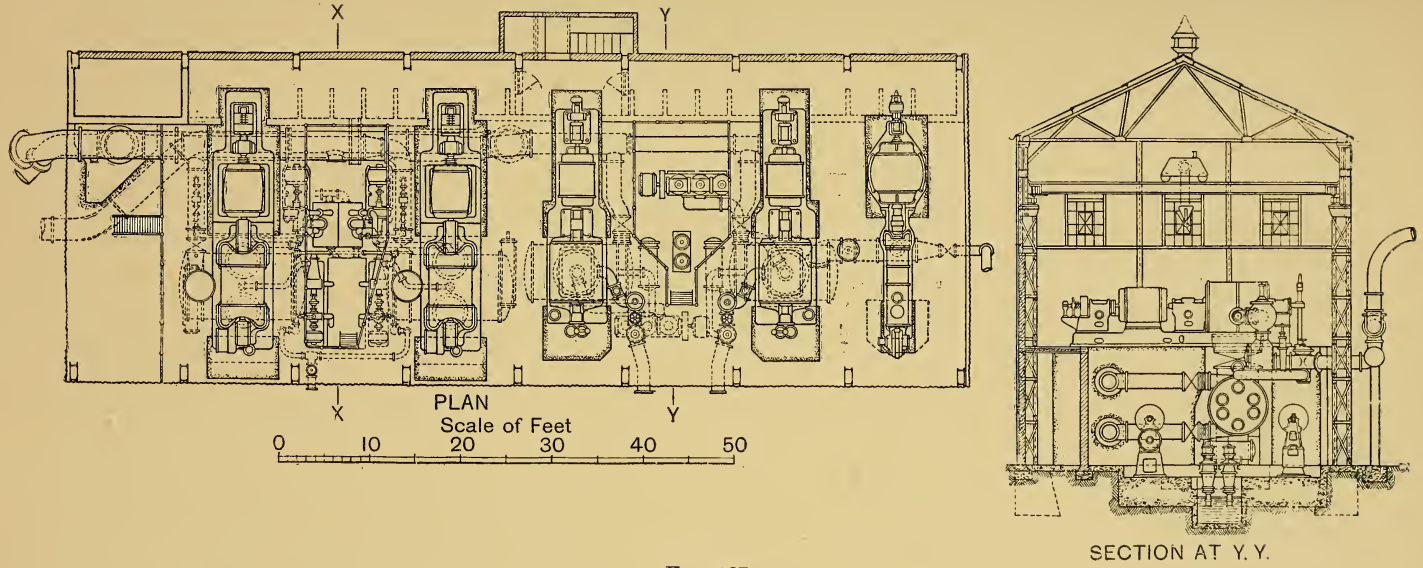


FIG. 127A.

CHAPTER IX

HYDRO-ELECTRIC POWER HOUSES

THERE are many countries which are favoured with water power. In America, the famous falls of Niagara and other falls in Canada and on the flanks of the Rocky Mountains; in South America along the flanks of the Andes and Cordilleras or in Brazil; in Africa, India, Italy, Switzerland, Sweden and Norway, there are enormous natural forces which can be, and are being, utilized through the agency of electrical transmission for the use and convenience of man. The commercial utilization of water power is dependent on three things: (*a*) the capital cost involved in the purchase of the water rights, embankment and training of the falls, construction of the head and tail races or pipe line and power house; (*b*) the capital cost of, and annual loss in the upkeep of the transmission lines; (*c*) comparative costs of (*a*) and (*b*) turned into annual costs of production and that of a steam or gas-driven station, dependent on coal, and the cost of coal, delivered at possibly some more convenient and nearer site.

Selection of Site.—In settling the site of a hydro-electric power house the following matters must be considered.

(*a*) Storage of water and available supply, based on the watershed, average rainfall, and minimum rainfall, all of which affect volume of storage water necessary.

(*b*) Available head of water, taking into account both the minimum head in the reservoir after drought, and the piling up in the tail race caused by the turbine discharge, or by floods.

(*c*) Character of the rock or stratum forming the river-bed.

(*d*) Capital cost, as above, of water rights, masonry, and of the power house completely equipped.

(*e*) Length and cost of transmission line.

Upon these factors will depend the cost per unit delivered at the receiving end, and therefore the cost per horse-power year, or per K.W. year.

To the above items may be added the cost of ice racks and barriers in sources of supply affected seriously by winter conditions.

Classes of Supply.—It is customary in some countries to give three classes of supply, viz.—

(*a*) Guaranteed full year supply.

(*b*) Supply for restricted hours.

(*c*) Supply liable to be cut off in periods of severe drought or under exceptional wintry conditions.

A careful survey has to be made of the country, so as to locate the best position of the power house, and difficult civil engineering operations have frequently to be undertaken. Sometimes it may be found cheaper to build a long head race or canal, or to excavate a tunnel, or to lay long lines of pipes, sometimes it may be cheaper to excavate a longer tail race. At other times the latter may be partly filled up with detritus brought down with the water, or the flood water may pile up so as greatly to reduce the head, and this depends on the nature of the rock through which the tail race is cut. At times considerable preliminary operations, involving the diverting of a very considerable volume of water, have to be undertaken, so as to enable the head race to be soundly constructed. Such a case arose at Gullspång, in Sweden, where an expensive tunnel had to be cut through gneiss to carry away the water, while the original river-bed was prepared and strengthened to enable the power house and turbine sluices to be constructed. Lengthy tail races are generally to be avoided, since in addition to the piling up of the backwater, they are liable to freeze in some climates. The tail race must be arranged to discharge parallel with the natural stream of the river.

Measurement of Water Flow.—A few preliminary remarks as to the measurement of water flow will be useful to the designer.

The velocity (in feet per second) of water in motion is equal to the square root of the head in feet multiplied by twice the gravity value, 32·2, or $v = \sqrt{2gh}$, or more simply $= 8{\cdot}03\sqrt{h}$.

(*a*) To measure the volume of water flowing at any particular

point a fairly accurate calculation can be made by constructing a weir as shown in Fig. 128. Francis has determined that in such

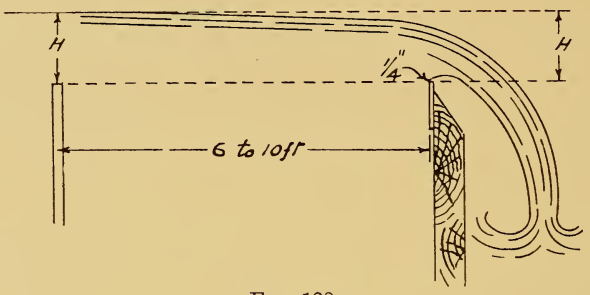


Fig. 128.

cases the volume of water flowing in cubic feet per minute is given by the formula

$$I = CB\sqrt{H3}$$

where C = 199·8, and B = width of weir in feet and H the true depth of water on the weir in feet, and where the weir is the full width of the stream measured.

If the weir is contracted on one side or both, then the formula becomes (n being the number of contractions)—

$$I = 199{\cdot}8(B - CI\,nH)\sqrt{H3}.$$

(b) In other cases it is necessary to use a submerged weir so

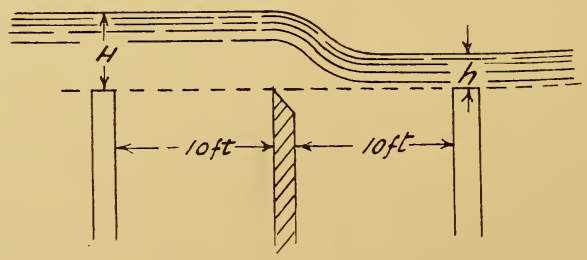


Fig. 129.

as not to raise the level of the water more than possible. When a weir of the form shown in Fig. 129 is adopted, the volume of

water is then $KL\left(H\frac{h}{2}\right)H - h$; K being a coefficient depending on the value of $h - H$ and having the following values :—

$h-H$	K
0·2	3·3 -3·36
0·4	3·15-3·21
0·6	3·12-3·17
0·8	3·11-3·16
0·9	3·15-3·21

The accuracy of the weir method is stated to be within 4 per cent.

(*c*) The flow of water may also be measured by a float at various points—not less than 10—across the width of the stream, selecting a place where the banks are somewhat parallel and the bottom fairly smooth. The average time taken to float between two points of observation is then noted. The float should be cylindrical and so weighted that the submerged end is only just clear of the bed of the stream, if shallow. A survey is then made of the bed of the stream so as to get its sectional area, measured from the top of irregularities such as boulders lying in the bed of the stream. The average area of the stream in square feet multiplied by the ascertained average velocity in feet per minute will give the flow in cubic feet per minute. The accuracy of this method is stated to be within 12 per cent.

(*d*) Finally, the velocity may be measured by a meter either of the revolving type, having vanes rotated by the water current, or by a deflecting meter, in which a vane is deflected by the current and brought back to zero by the torsion of a steel wire. The readings of the meter are then referred to tables, which give the flow of water within 10 per cent.

These meters are read about one foot below surface at each of the points where the contour of the bed is taken, and the average readings thus obtained multiplied by 0·85 to get the average velocity, or the meter can be slowly lowered to the bed at each measuring point and slowly raised to the surface, and the average at each point taken as the real measure. Or, again, the meter is held at a point 0·6 of the actual depth of the stream at that place, and the average of all readings so taken across stream may be taken as the real value.

Each method should be tried successively and a mean taken of the three. Both minimum flow and flood-water observations must be taken.

A further rough check can be made on a river flow by ascertaining the average and minimum rainfalls and the area of the watershed drained by the river in question. The flow by actual measurement will, of course, be a good deal less owing to the effect of evaporation, underground springs and streams, etc., and the various geological conditions.

The construction of dams is often necessary to raise the available head and to increase the storage of water.

Construction of Dams.—In the construction of dams expert civil engineering and geological knowledge are required; excavation into rock so as to effect a good junction between the concrete dam and solid rock, elimination of leakage, with its possible underpinning of the dam, the effects of springs, or of ice-floes, flood waters, etc., all call for a special experience in this important class of work, and assistance from those who have had experience in these works should be obtained. A few observations may, however, be of use here.

The total pressure exerted on any dam is (see Fig. 130) equal

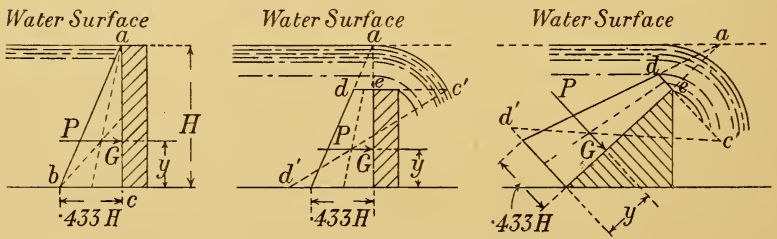


Fig. 130.

to the area of the pressure diagram, the centre of the pressure passing through the centre of gravity perpendicular to the dam surface.

The pressure at any point, in lbs. per sq. inch is P = 0·433D, where D = depth from surface.

The moment about x is M = Py, and the total pressure in lbs. exerted on any dam is

$$P = 0{\cdot}433HA$$

where A is the area of submerged dam in square feet, and H the head of water in feet above the geometrical centre of the submerged portion of the dam.

As an example of a recently constructed dam, Fig. 131 shows a section of the river-bed and an elevation and plan of the dam at Gullspäng, situated between the lakes of Skagen and Vänern,

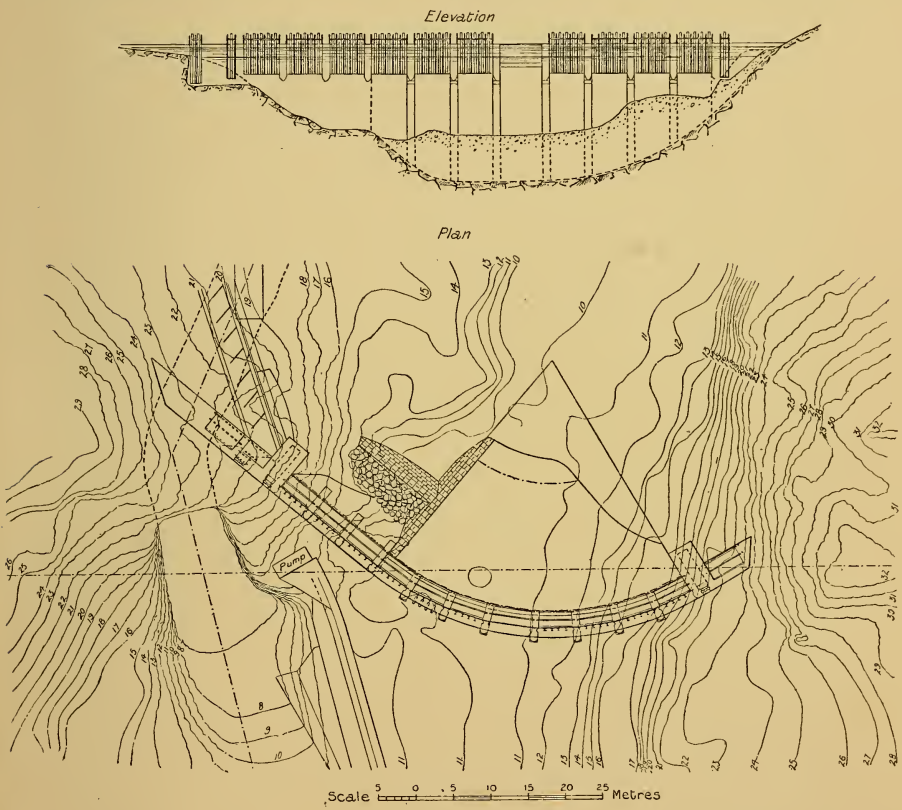


Fig. 131.

Sweden, and described by A. V. Clayton, *Inst. Elect. Engineers*, vol. 45, 1910. It will be seen that the rock underlay the river-bed at some depth.

A straight part of the dam was constructed on the gravity principle built directly on the solid rock bed. This was brought

out as far as possible so as to reduce the arched portion. The arched part of the dam depends for its stability on its arch-like property, the crown being against the stream or head of water and buttressed against the straight parts of the dam on each side, which thus act as abutments. The employment of this method enabled a great saving to be made both in the amount of excavation and in the materials employed. Fig. 131 shows that the section of the river-bed which would otherwise have had to be excavated is practically equal to the profile of the dam itself. If the extra width of base required for a gravity dam be calculated, it will be found that the cubical contents of this extra portion are as great as those of the existing dam, or if a gravity dam had been constructed throughout, double the quantity of the actual materials used would have been required in addition to all the extra excavation.

The face of the dam is rendered with cement, and the bottom caulked with stamped clay to prevent leakage. Fifty regulating sluices are provided grouped in ten openings of five each. The sluices are constructed of wood working in 1 section steel girder frames. In this case a large spillway is provided in the middle of the dam, to clear away loose ice. A salmon pass and two eel passes are provided.

Storage of Water.—A storage basin is often of great importance in water-power plants, especially with intermittent loads, or on an average daily load curve. If the average head lasts, say, for eight hours a day, then the storage basin should be of sufficient size to accumulate the average flow for the remaining sixteen hours a day. The turbines can then be supplied direct during the eight hours' average demand, not only by the average flow during that period, but also by the accumulated supply, and thus the useful power is increased threefold. The amount of working depth in the storage basin depends on the manner in which the turbine speed will be affected.

Formation of ice in shallow basins, and also evaporation have to be allowed for. In the former case the amount of storage lost is the proportion of the depth displaced by the ice to the working depth of the storage basin.

Table No. CVII. gives the average kilowatt-hours per acre-foot of storage area for heads varying from 5 to 1000 feet.

TABLE CVII.

AVERAGE KILOWATT-HOURS AND HORSE-POWER HOURS STORED IN EACH ACRE-FOOT WITH DIFFERENT HEADS.

Head.	Available energy.		Head.	Available energy.		Head.	Available energy.	
ft.	H.P. hrs.	K.W. hrs.	ft.	H.P. hrs.	K.W. hrs.	ft.	H.P. hrs.	K.W. hrs.
4	5·5	4·103	150	206·25	153·863	580	797·50	594·93
5	6·88	5·129	160	220·0	164·120	590	811·25	605·19
6	8·25	6·155	170	233·75	174·378	600	825·00	615·45
7	9·62	7·180	180	247·50	184·635	610	838·75	625·71
8	11·00	8·206	190	261·25	194·893	620	852·50	635·96
9	12·37	9·232	200	275·00	205·150	630	866·25	646·22
10	13·75	10·258	210	288·75	215·408	640	880·00	656·48
11	15·12	11·283	220	302·50	225·666	650	893·75	666·74
12	16·50	12·309	230	310·25	235·923	660	907·50	676·99
13	17·90	13·335	240	330·00	246·180	670	921·25	687·25
14	19·24	14·361	250	343·75	256·438	680	935·00	697·51
15	20·62	15·386	260	357·50	266·69	690	948·75	707·77
16	22·00	16·412	270	371·25	276·95	700	962·50	717·92
17	23·37	17·438	280	385·00	287·21	710	976·25	728·18
18	24·75	18·464	290	398·75	297·47	720	990·00	738·44
19	26·13	19·489	300	412·50	307·72	730	1003·75	748·70
20	27·50	20·515	310	426·25	317·98	740	1017·50	758·95
21	28·87	21·54	320	440·00	328·24	750	1031·25	769·21
22	30·25	22·566	330	453·75	338·50	760	1045·00	779·47
23	31·62	23·592	340	467·50	348·75	770	1058·75	789·72
24	33·00	24·618	350	481·25	359·01	780	1072·50	799·98
25	34·37	25·644	360	495·00	369·27	790	1086·25	810·24
26	35·75	26·670	370	508·75	379·53	800	1100·00	820·50
27	37·12	27·699	380	522·50	389·78	810	1113·75	830·76
28	38·49	28·72	390	536·25	400·04	820	1127·50	841·01
30	41·25	30·772	400	550·00	410·30	830	1141·25	851·27
32	44·00	32·824	410	563·75	420·56	840	1155·00	861·53
35	48·12	35·901	420	577·50	430·81	850	1168·75	871·79
40	55·00	41·130	430	591·25	441·07	860	1182·50	882·04
45	61·87	46·159	440	605·00	451·33	870	1196·25	892·30
50	68·75	51·288	450	618·75	461·59	880	1210·00	902·56
55	75·62	56·416	460	632·50	471·84	890	1223·75	912·82
60	82·50	61·538	470	646·25	482·10	900	1237·50	923·07
65	89·37	66·667	480	660·00	492·36	910	1251·25	933·43
70	96·25	71·803	490	673·75	502·62	920	1265·00	943·69
75	103·12	76·931	500	687·50	512·87	930	1278·75	953·98
80	110·00	82·060	510	701·25	523·13	940	1292·50	964·20
90	123·75	92·318	520	715·00	533·39	950	1306·25	974·46
100	137·50	102·575	530	728·75	543·65	960	1320·00	984·72
110	151·25	112·833	240	742·50	553·90	970	1333·75	994·98
120	165·00	123·092	550	756·25	564·16	980	1347·50	1005·23
130	178·80	133·348	560	770·00	574·42	990	1361·25	1013·49
140	192·50	143·605	570	783·75	584·68	1000	1375·00	1025·75

As the load on a power house is generally intermittent, and moreover as the rainfall in most districts is also variable, a reservoir becomes necessary with most hydro-electric power plants.

But the cost of impounding is also a factor which requires considerable attention. Not only have costly masonry dams to be provided, the cost of which will depend on the geological contours, the rates for local labour, facilities of transport, local stone available, but also on the physical conditions of the river itself. These may even require the complete diversion of the stream temporarily, thus involving heavy preliminary costs. Spill-ways for excess or compensation water, sluices properly proportioned to control the flow under the varying conditions, salmon and eel passes, so as not to interfere with the fishing rights, construction of the tail races to prevent flooding and undue raising of the backwater level, are some of the many points requiring actual experience in this class of work. In other cases where pipe lines are used a careful survey has to be made so as to get the best and easiest line possible, and to fix the pipes in position under the least costly conditions, to avert landslides, to provide for the construction of relief ways, and so forth. All these call for the best applied civil engineering practice, so as to utilize the available water to the best advantage and under the best commercial conditions. Every additional hundred pounds spent unnecessarily becomes practically a permanent charge on the undertaking.

The effect of ice has to be considered, and the amount of storage lost will be that due to the proportion of the mean depth of the reservoir and the displacement by the ice.

Head Races and Penstocks.—The flow of water in cubic feet per second is as follows :—

(*a*) Rectangular openings of length L and depth D, both expressed in feet :—

$$I = 4{\cdot}812LD\sqrt{H}.$$

(*b*) Circular openings of diameter D feet, where H is greater than DD :—

$$I = 3{\cdot}78D_2\sqrt{H}.$$

(*c*) Through a pipe or canal (Kutter) :—

$$I = CA\sqrt{S}\sqrt{R}.$$

A being the wet area, S the fall in feet per foot, R the mean hydraulic radius in feet, C a constant dependent on the coefficient of roughness N, and H the head of water.

The flow of water through a pipe depends on the head, the length of pipe and the bends, and the coefficient of roughness N. The total resistance to flow is made up of three components—

(*a*) Velocity head or the height through which a body must fall to acquire the velocity of the water in feet per second flowing through the pipe—

$$Hv = \frac{v^2}{2g}.$$

(*b*) Entry head, or that necessary to cause the fluid to enter the pipe, roughly half the velocity head.

(*c*) Friction head, or that necessary to overcome the friction in the pipe. If the pipe line is very short, a maximum velocity of $0{\cdot}1\sqrt{2gH}$ may be adopted; but if the pipe line is long, this velocity must be reduced so as to avoid friction losses. The following values of roughness N are generally taken:—

0·012 for concrete and open wood flumes, pipes 3 feet and more in diameter, with high velocities.

0·013 for pipes from 3 feet to 6 feet in diameter, with low velocities and for large cement-rendered tunnels.

0·0135 for brickwork penstocks over 3 feet in diameter, cast iron and steel riveted pipes from 8 to 20 inches in diameter under 75 to 150 lbs. pressure.

0·015 rough concrete races or tunnels where the interior faces are not smooth rendered with moderate velocities, and for open concrete canals with low velocities.

0·017 for tunnels in hard rock roughly faced, and very large open concrete-lined canals.

0·02 for races lined with rough masonry, canals in earth, etc.

Design of Power Houses.—In the design of power houses for hydro-electric work, care has to be taken in the selection of materials, as otherwise accidents may happen causing loss of life and a shut down of the plant. For instance, formerly the outer cases of flumes were made of cast iron, a practice now abandoned. In one case an outer case burst owing to a flaw in the casting, thereby causing loss of life and much damage to the plant before the inlet gates could be shut.

The lower portions of power houses are usually constructed of concrete—sometimes reinforced—and the upper parts, above

flood-level, of brickwork. Very heavy dead weights have to be supported, and very heavy thrusts and tilting effects due to the water pressure have to be provided for.

The design should provide for expansion and contraction, so as to eliminate chances of cracks in the concrete. Thus it is best to construct the forebays each by itself, unconnected with each other. The effects of severe frosts on cracks in the concrete have to be considered, and thus great attention must be paid to this, and also to the chances of leakage between the plate flumes and the concrete, while at the same time allowing for differences of expansion between the flume plates and the surrounding concrete.

Classification of Falls.—Water power houses may be subdivided into three classes :—

(*a*) Low head, say, from 5 to 25 feet.

(*b*) Medium head from 25 to 50 ,,

(*c*) High falls from 50 to 250 or more feet.

Water Turbines.—Turbines may be broadly classed into—

(*a*) Low-head turbines, reaction type, practically the inverse of a screw propeller.

(*b*) High-pressure turbines, impulse or impact type operated by the direct pressure of a water jet directed from a nozzle.

These again may be subdivided into types, viz.—

1. Radial flow, either centrifugal or outward flow or inward flow.
2. Tangential flow, as in the Pelton wheel.
3. Axial flow.

Modern practice, however, tends to the adoption of—

(*a*) The inward flow, reaction type for low and medium falls—say up to 50 feet; and

(*b*) the impulse, tangential flow type for high falls.

But special wheels are usually designed, as there is a critical speed at which turbines are most economical. If the speed is increased without a decrease in the diameter, the efficiency is reduced. The peripheral speed must not vary much from the theoretical velocity which water will have from falling freely through a height equal to the head acting on the wheel measured from head to tail water $\times$ 0·6. The theoretical velocity being 4·8H.

A low-head turbine will develop about 80 per cent. efficiency at full gate, and, say, 70 per cent. at nominal load. Full load

efficiencies of 85 per cent. can be obtained at heads of 30 feet to 950 feet.

Low Falls.—Fig. 132 shows the plan of a simple arrangement of a low-fall power house. A dam is constructed at A to raise the level and to provide storage. At B the intake allows the water to flow through sluices C to the penstock D, and thence into the head race E. Thence the water flows through racks F into the forebay G, thence through the turbines, controlled and regulated by gates. The turbines discharge into the tail pit H and tail race I to the downstream, or backwater.

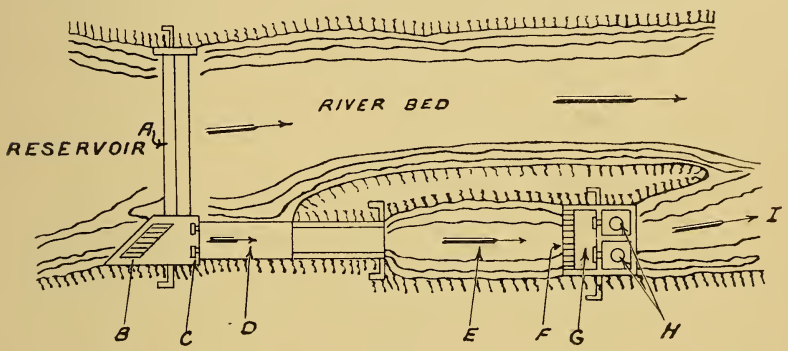


FIG. 132.

In low-fall plants the water is led to the turbine in an open head race in which the velocity is kept as low as possible, viz. about 2 feet per second, so as to minimize losses through eddies and friction. The guide vanes must be covered by at least 5 feet of water.

Again, in the tail race in very low falls the velocity should not exceed 2 feet per second, or at most 3 feet per second, with falls not less than 5 feet, as too high a velocity causes eddy currents and destroys the suction action through the admission of air.

Where a suction pipe is fixed it should be arranged to taper from the turbine runner downwards.

Low-head turbines require to be designed for as high a speed as is consistent with efficiency. Some of the older wheels were not direct connected to their generators, but through the intermediary of gears, thus reducing the efficiency and increasing the cost.

A good method of fixing turbines for power houses is shown in Fig. 133. There are two wheels on a single horizontal shaft within a steel casing. The water is delivered to the centre of the casing and thence discharges right and left to draught tubes, thus

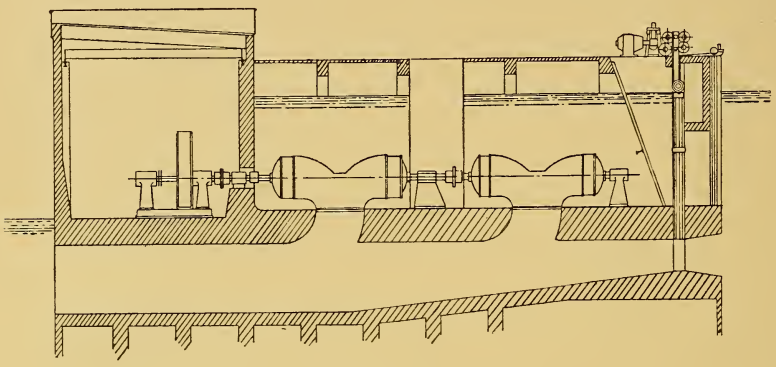


FIG. 133.

neutralizing thrust on either bearing, allowing accessibility to the shaft for the direct coupling of the generator, and, owing to the direction of the streams, avoiding eddies in the water and loss of efficiency.

Some particulars of low-head turbines are given in Table CVIII.

TABLE CVIII.

Brake H.P.	Speed R.P.M.	Head of water.	Cubic feet per min.	Diameter of wheel or numerical inches.	Type.
		ft.			
309	249	25	8050	34	Vertical.
292	220	25	8354	48	do.
265	88	25	5614	68	Twin-horizontal.
308	214	25	8142	33	Vertical.
150	150	25	8284	42	do.
285	200	25	7434	34	do.

Vertical Shaft Turbines.—Fig. 134 shows the lay-out of twin turbines on a net head of only 10 feet at Avesta Lillfors, Sweden. They give 680 B.H.P. at 107 R.P.M., with an efficiency of 82½ per cent. at full gate. The upper wheel discharges upwards through a draft tube ; the lower wheel discharges downwards, and thus not

requiring one. An examination of Fig. 134 will show that the tail race level is sometimes higher than the upper end of the discharge casing of the upper turbine, while at other times during periods of low backwater the water is only level with the bottom

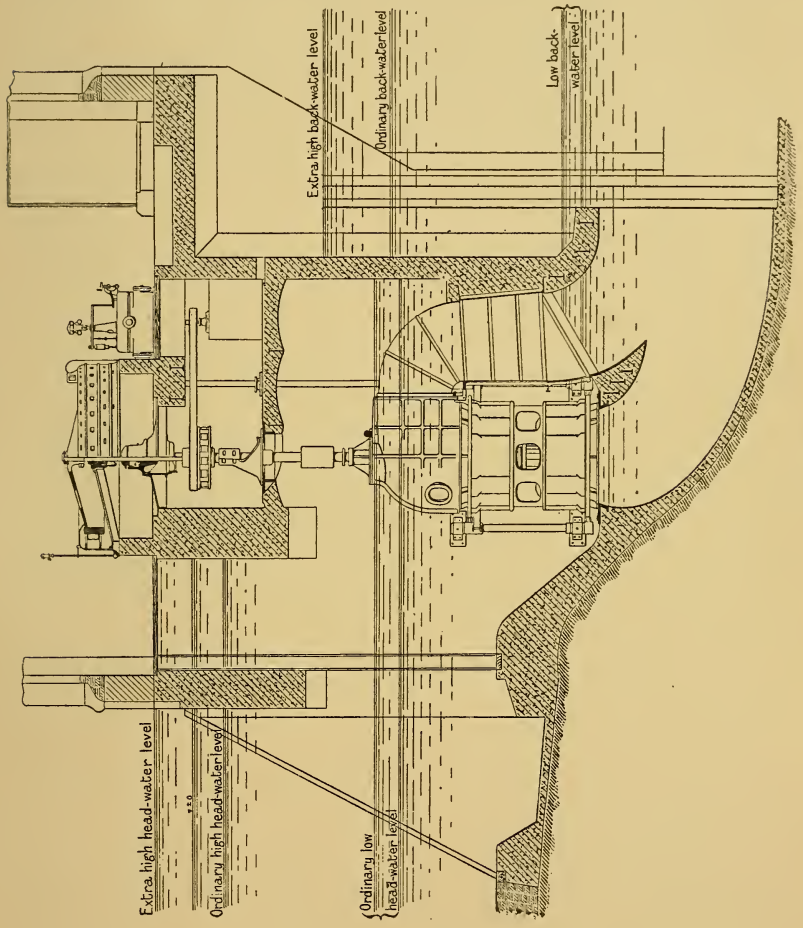


FIG. 134.

of the lower wheel, when the draft tube of the upper turbine then comes into use. This is a good case for the adoption of vertical shaft turbines, as if a horizontal type had been installed, the tail race level would have at times been considerably higher than the generator room floor level, which would have required the

generators to have been placed in a water-tight sunken chamber. In vertical shaft turbines the rotatory parts have of course to be suspended. These include a long and heavy shaft, the rotor of the generator, and the runners of the turbine. Many unsuccessful attempts have been made to take up this weight on ball bearings. These have been abandoned, and it is now usual to have hydraulic bearings which float the entire rotary system when the weight to be supported is too great to be taken up on the ordinary lignum vitæ footstep.

Falls as low as 6 feet are used. The power station at Korsnäs, Sweden, is worked at this low head. There are four pairs of turbines—eight runners in all—on one shaft, running at 107 R.P.M. and developing 420 H.P. The automatic governors are fixed on the floor above the generator room, as shown in Fig. 135.

Very low falls necessarily require very large volumes of water per B.H.P., and are thus relatively extremely costly to install per H.P. developed.

One method of increasing the speed on low-head turbines is that invented by Böving. There are two runners, revolving in opposite directions, the shaft of one being hollow, and the shaft of the other rotating within it. The field and the inductor of the generator are connected respectively to the two shafts, and both rotate, though in opposite directions, and thus the effect of doubling the speed is obtained.

Thus the generator has only one-half the number of poles for any given frequency, which it would have if the rotor alone rotated.

Vertical type turbines have advantages on low falls, and also with varying levels of the backwater. They are fixed in open flumes with the generator room floor above the flumes.

In the State of Indiana there is an 8-foot hydro-electric power station at Monticello. The variation between high and low water levels is about 5 feet. The extreme variations in flow are from 400 to as much as 16,000 cubic feet per second in time of flood. The dam is constructed at a place where the river is about 300 feet wide and 3 feet deep, the section across the stream being fairly uniform. The dam is of timber construction, the cribbing being of 12-inch by 12-inch timbering spiked together with

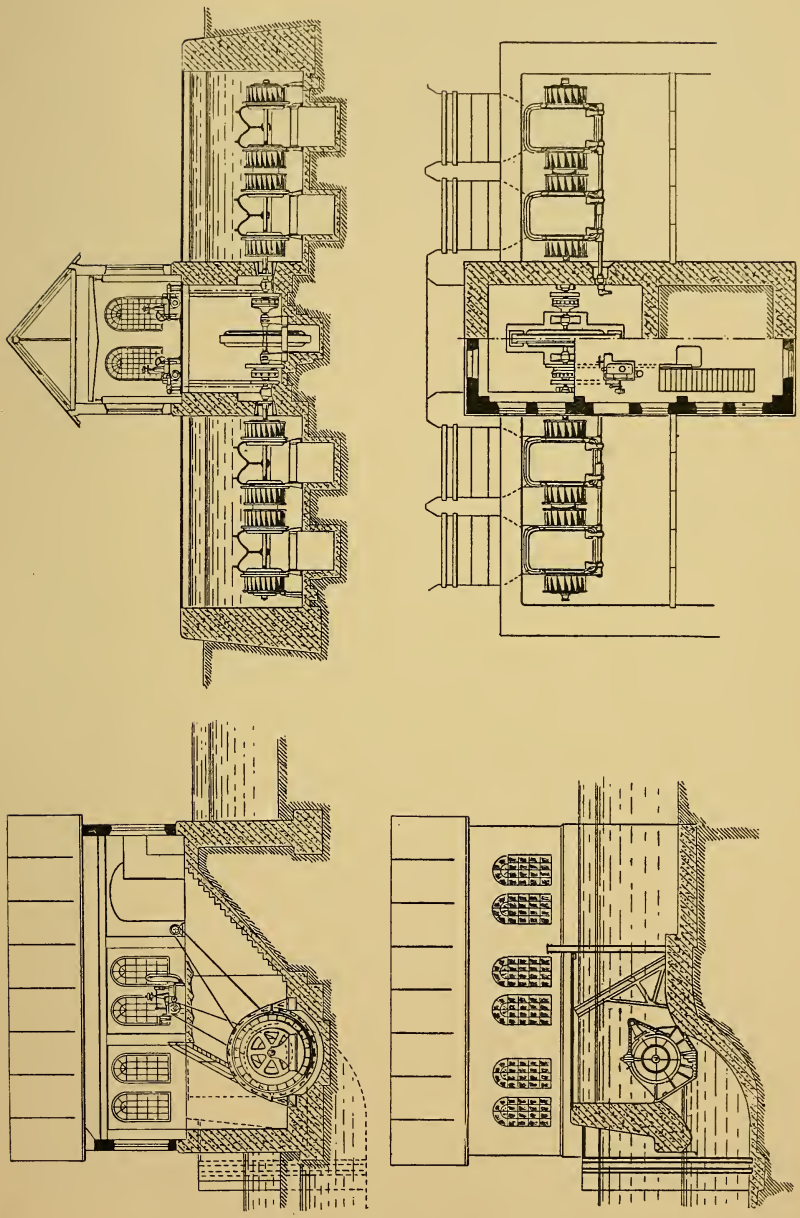


Fig. 135.

¾-inch drift pins. The turbine house forms part of the dam, thus avoiding the construction of a head race, and is built of reinforced concrete; a fish ladder and storm sluices are provided. The flood gates are operated by motors controlled in the turbine house. There are four vertical turbines, each wheel being in a reinforced concrete compartment, and developing 115 H.P. A log boom is fixed in front of the turbine house as a protection against ice. The turbines are all connected to one main shaft through clutches. The two generators are 250 K.W. and 150 K.W. respectively, 2200 volts 3-phase, 60 cycles. The total capital of the company is $100,000, and the charges are 10 cents. per unit, with discounts for lighting and 5 cents. with discounts for power and heating.

Medium Falls.—At Gullspäng, Sweden, an important power station has been erected with a 65-foot fall. In the construction of the dam, the river had to be temporarily diverted, and a tunnel was blasted in the neighbouring gneiss, 60 yards long by 30 feet in diameter. The exposed river-bed at the site of the dam was found not to be wholly of rock, and considerable excavation would have been necessary to reach solid rock across the whole width, at a great expense. An arch-formed dam as shown in Fig. 131, previously referred to on p. 303, was constructed in consequence, with the straight sides of the dam, founded on solid rock, acting as abutments. The middle part of the dam is an arch, depending on this for its stability, the crown of the arch being against the stream, and the thrust being taken up by the abutment or straight sides of the dam. The front of the dam is faced with cement and the bottom caulked with stamped clay. There are fifty regulating sluices, each of timber working in steel girder frames in ten openings of five apiece. There is an open canal from the head race to the wheel house, the bottom of which is in solid rock with concrete walls.

Fig. 136 shows a section through the power house, showing the forebay, ice racks, sluices, flume, turbines, draft tube, and tail race.

The twin type turbines are each of 5000 H.P. or 2500 H.P. per wheel running at a normal speed of 250 R.P.M., and with their supply pipes and draft tubes, cement coated, are supported on a floor of heavy steel girders and reinforced concrete.

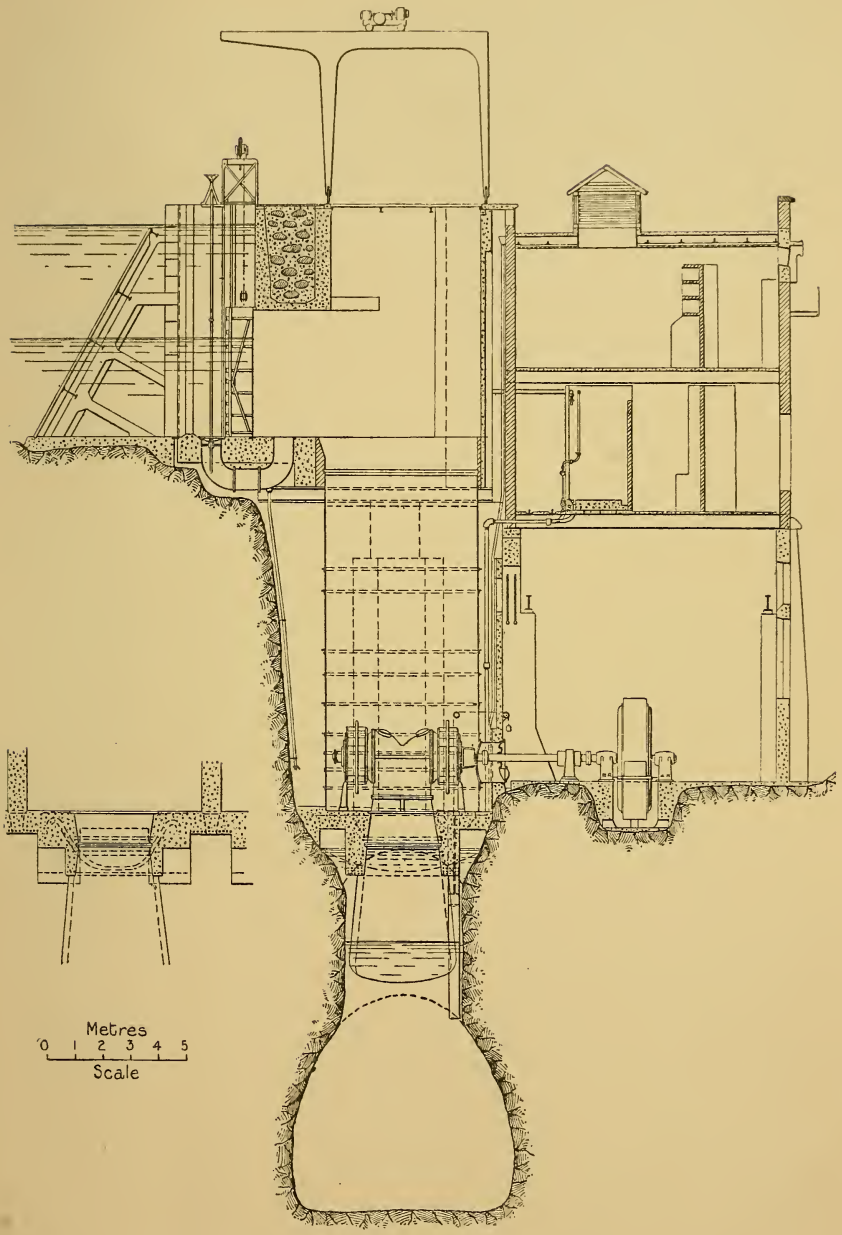


FIG. 136.

The turbine runners carry boiler plate buckets formed to the correct shape, cast into an iron hub and ring. This type provides a smooth and even bucket, minimizing skin friction, of strong construction and preferable to a cast bucket, which may be damaged by stones, ice, etc., coming over with the water. The chutes leading the water into the wheel are movable on pivots, and by moving these the openings between them are varied, and regulation effected in a way which ensures the projection of the water on to the buckets at the correct angle, thus improving the efficiency at light loads.

Fig. 137 shows the efficiency curve of one of these machines.

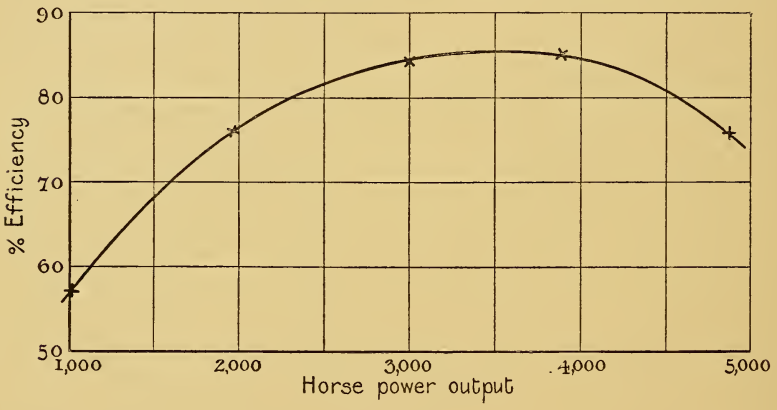
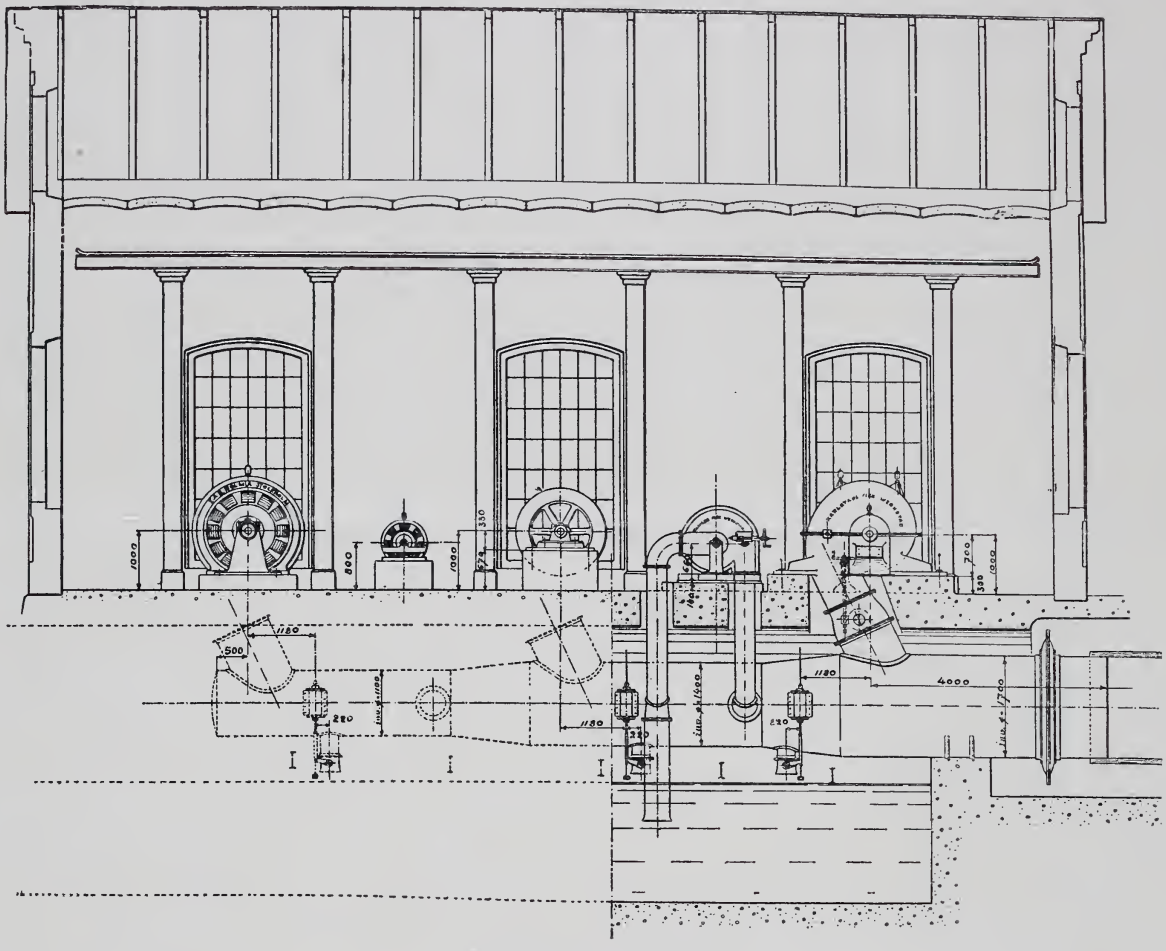
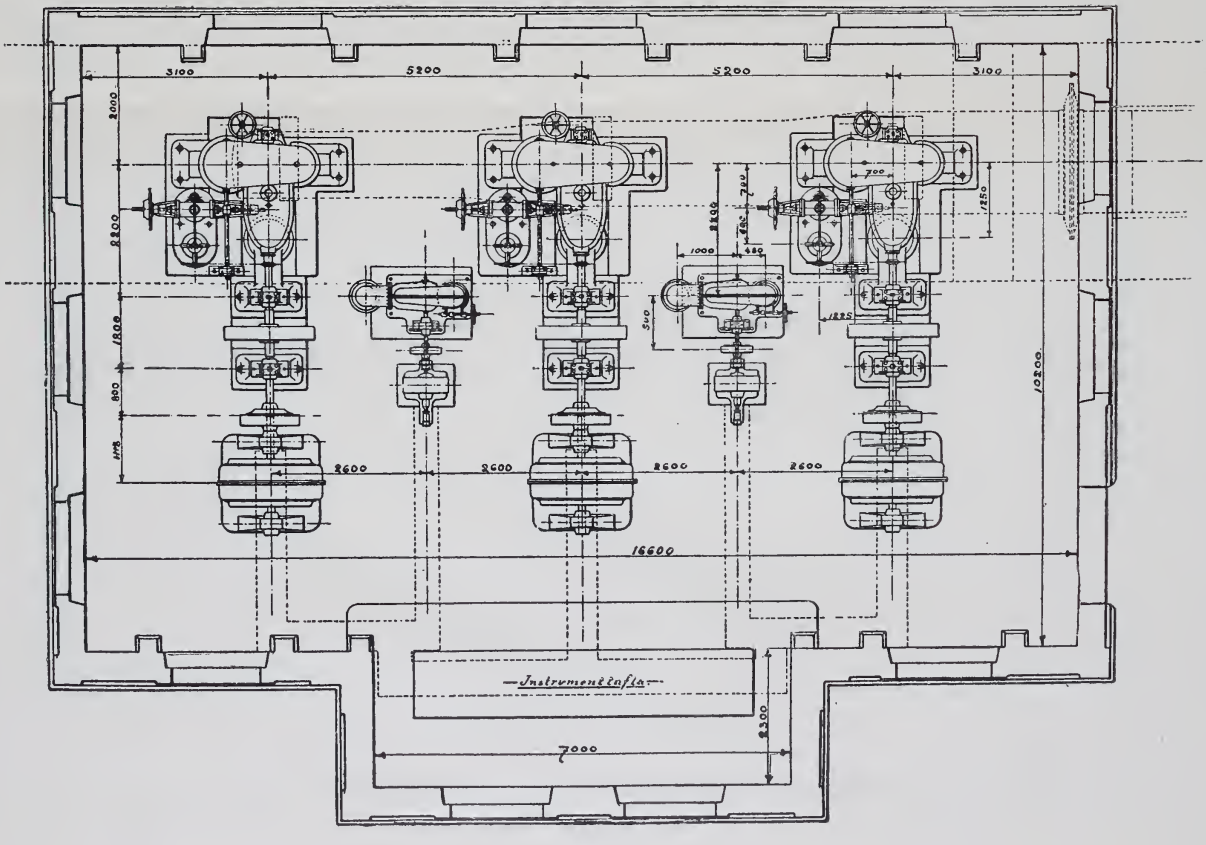


Fig. 137.

The turbines are placed in open vertical flumes built of boiler plate, each 43 feet long by 18 feet diameter, two 5000 H.P. sets in each flume. Each flume was well greased before the concrete was formed around it so as to allow for expansion, and has its own forebay, ice rack, and head gate. The latter are 18 feet wide by 15 feet high, and consist of semi-cylinders of iron plates stayed with horizontal struts, faced with oak sliding surfaces. The gates are too large to operate against the water pressure, and so are arranged with bye-passes to fill the forebays and equalize the pressure. The turbine speed regulation is governed by automatic hydraulic regulators operating directly in the movable chutes referred to above. The governor is driven from the turbine shaft, and controls a small valve and admits water to either end of a relay



Longitudinal Section.



Plan.

PLATE IX.—ÅTVIDABERG HYDRO-ELECTRIC POWER HOUSE. [*To face page* 317.

cylinder, as the speed rises or falls. The relay piston operates the movable chutes through a rack and segment. The tachograph records of these machines showed that the variation of speed was only 5½ per cent. on the imposition of full load to the turbine running light, or on throwing off the full load, and 2 per cent. for variations amounting to half the rated load; there being absolutely no hunting effects.

The plant at Gullspäng aggregates 16,500 H.P., and the total cost of the power house and its equipment was £10·5 per H.P. This includes the complete hydraulic equipment for a larger power house, 25,000 H.P. Thus, when completed, the estimated final cost will be reduced to £7·75 per H.P.

Another medium-fall equipment has been fixed at Alby, Sweden, for the electrical production of calcium carbide, etc. In this case the intake canal is built partly of ordinary earthwork with a timber sponting or core to prevent leakage fixed in the middle of the walls, and partly of masonry.

The velocity of the water in the earthwork portion is 1 foot per second, and 1·6 foot per second in the masonry length. A settling pond was formed at the end of the race, whence wrought-iron pipes 6 feet and 8 feet in diameter conduct the water to the turbines. These tubes are 72 feet in length and the velocity of the water in them at full load 5·5 feet per second. The turbines are fixed in flumes above the tail race level, and the available head varies from 69 to 75 feet, of which 15 feet are due to the suction draft tubes. The tail race is 160 yards in length, and the velocity of water varies from 2·3 feet per second to 3·3 feet per second.

Plate No. IX. shows the longitudinal section and plan of the Åtvidaberg Power House. The net head is 66 feet, and three generator turbines by Oscar Boving & Co. have been fixed, each developing 200 H.P. at a normal speed of 500 R.P.M., and two exciter turbines each of 15 B.H.P. at a speed of 1000 R.P.M. The pressure pipe is, as shown in the figures, carried in a trench underneath the generator room floor, with skew branches to each turbine. The efficiencies obtained are—

Full load	81·9	per cent.
¾ „	82·0	„
½ „	81·6	„

High-pressure Turbines.—Tangential water wheels are usually used in high-pressure work, the wheels being driven by the direct force of a high-pressure jet of water directed through a nozzle, and also by the reactive effect of the water upon the buckets after it has reached them, and obtained through curving the buckets so that the water jet is completely reversed in direction. Split buckets are used, so that the jet is divided and the side thrust neutralized.

Fig. 138 represents a two-jet Pelton wheel as manufactured by

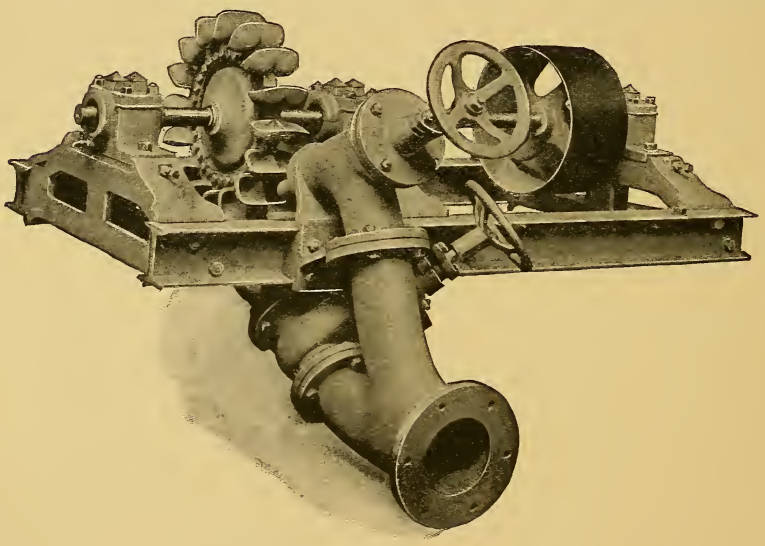


Fig. 138.

Gilkes & Co., England, whereby a higher speed is obtained with a smaller wheel.

Some makers use an ellipsoidal bucket with the lip cut away to clear the jet, and others a cup-shaped bucket, which is an intermediate design between the two kinds above mentioned.

The design of nozzles varies; but it is now customary to adopt the needle regulating type, by which the stream issuing from the nozzle is smooth and solid, and free from the spraying appearance of an ordinary jet.

There are also many types of governor, and successful devices can now be obtained for acting through the agency of hydraulic

pistons directly upon the gates, and so devised as to obviate hunting. The whole object of a well-designed governor for water wheels is to get a sensitive and positive control of the gates, without any danger either of overrunning or of hunting.

Vertical turbines take up less room than the horizontal types; but they involve, as a rule, greater cost in foundations, and moreover require step bearings and auxiliary apparatus, and are best avoided with high-pressure turbines. So as to reduce the load on a step bearing, the vertical turbine is usually designed to run at the highest speed. This favours the generator efficiency, but reduces the turbine efficiency. Highest efficiency and durability of the parts require normal reaction and limited dimensions of the runner. The peripheral speed of the runner is fixed by the head of water. Power is proportional to the square of the diameter and inversely proportional to the square of rotation.

An increase of rotation means proportionately less power, and results in inefficient reaction at the buckets, reduced area of

TABLE CIX.

Items.	24 hours' power capacity.					
	50,000 H.P. development.		75,000 H.P. development.		100,000 H.P. development.	
	$	£	$	£	$	£
Tunnel tail-race . .	1,250,000	260,417	1,250,000	260,417	1,250,000	260,417
Headworks and canal	450,000	93,750	450,000	93,750	450,000	93,750
Wheel-pit	500,000	104,166	700,000	145,833	700,000	145,833
Power house . . .	300,000	62,500	450,000	93,750	600,000	125,000
Hydraulic equipment .	1,080,000	225,000	1,440,000	300,000	1,980,000	412,500
Electric equipment .	760,000	158,333	910,000	189,583	1,400,000	291,667
Transformer station and equipment . .	350,000	72,917	525,000	109,375	700,000	145,833
Office building and machine shop . .	100,000	20,833	100,000	20,833	100,000	20,833
Miscellaneous . . .	75,000	15,625	75,000	15,625	75,000	15,625
	4,865,000	1,013,541	5,900,000	1,229,167	7,255,000	1,511,458
Engineering and contingencies, 10 per cent.	486,500	101,354	590,000	122,916	725,500	151,145
	5,351,500	1,114,895	6,490,000	1,352,083	7,980,500	1,662,603
Interest two years at 4 per cent. . . .	428,120	89,191	519,200	108,166	638,440	133,008
	5,779,620	1,204,086	7,009,200	1,460,249	8,618,940	1,795,611
Per horse-power .	115·57	24·082	93·45	19·47	86	18

discharge, abrupt changes of direction of flow and an overworked wheel. It is therefore necessary so to proportion the speed of the turbine as to get the normal reaction at the buckets and good proportion without sacrificing the generator, and this can best be arranged in a horizontal type.

In 1906 Reports of the Hydro-Electric Power Commission of the Province of Ontario estimates are given of the cost of generating plant at Niagara Falls, where a head of about 300 feet is obtainable. Table CIX. is taken from that Report, and the capital costs in £ sterling as well as in dollars are given.

Table CX. gives the estimated annual operating charges at the power house.

TABLE CX.

Items.	50,000 H.P. development.		75,000 H.P. development.		100,000 H.P. development.	
	$	£	$	£	$	£
Operating expenses, including administration	57,900	12,062	70,200	14,625	86,300	17,979
Maintenance and repairs	115,700	24,104	140,400	29,250	172,600	35,958
Replacement fund . .	86,800	18,083	105,300	21,937	129,500	26,979
Interest at 5%. . . .	231,400	48,208	280,800	58,500	345,200	71,917
	52,500	10,937	65,000	13,542	77,500	16,146
Total yearly charges .	544,300	113,394	661,700	137,854	811,100	168,978

The following Table, No. CXI., gives the general expenditure on an American hydro-electric system operating on a pressure of 100,000 volts operating over a radius of 200 miles, and having 40,000 K.W. of plant installed.

TABLE CXI.

Items.	Total capital expended.	Capital per K.W.	Operation expenses.	Annual capital charges.	Total annual expenditure.
	£	£	£	£	£
Dams	900,000	22·50		72,000	
Pipe lines and tunnels	750,000	18·75	15,000	75,000	215,000
Power station building	200,000	5·00		16,000	
Power house equipment	370,000	9·25		37,000	
Transmission lines .	560,000	14·00	12,000	56,000	68,000
Sub-station buildings	74,000	1·85	12,000	7,400	31,400
do. equipment	120,000	3·00		12,000	
Total . .	2,974,000	74·35	39,000	275,400	314,400

These figures may not be of much real value, as each scheme must depend so much on local facilities for building, such as the length and height of dam, geological surroundings, adaptability to the construction of the dam, contour lines of the surrounding country and especially of the area impounded, difficulties of river diversion during construction of the dam, local building stone, etc., as well as transportation facilities for the plant installed. But the example given is fair for general reference and typifies the general cost of a large installation.

Ontario Power House.—A description of the Ontario Power Company's Station may be taken as typical. This was fully given in an excellent paper by P. N. Nunn before the American Institute of Electrical Engineers, 1905. The Author has extracted some of the salient points in the power house design. Fig. 139 shows a map of the Niagara Falls with the power houses. From the head gates three steel and concrete tunnels, carrying 12,000 cubic feet per second, conduct the water to the top of the cliff above the power house, whence twenty-two steel penstocks conduct the water to twenty-two horizontal turbines.

The intake works are located with special regard to the ice difficulties. Cake ice in enormous quantities is carried down from the lakes for weeks at a time, and a long tapering forebay, the entrance to which is protected by the main intake, terminates in a deep spillway, as shown in Fig. 140. On the river side the forebay is enclosed by a submerged wall. The other side is occupied partly by a screen house leading to the inner bay and to the head gates.

The intake, 600 feet long, is almost parallel with the current in the river, and a concrete curtain wall, as shown in Fig. 141, extends 9 feet into the water, 15 feet deep at this point. Thus the gate openings beneath the curtain admit only deep water, and this only at right angles to the swiftly flowing surface water, which carries off the pack ice to the rapids beyond.

This operation is repeated at the main screen. A section through the screenhouse is shown in Fig. 142. This, again, lies parallel to the flow in the bay, and is so constructed that the front wall of the superstructure forms a curtain, admitting only deep water to the screens, excluding the surface water and ice

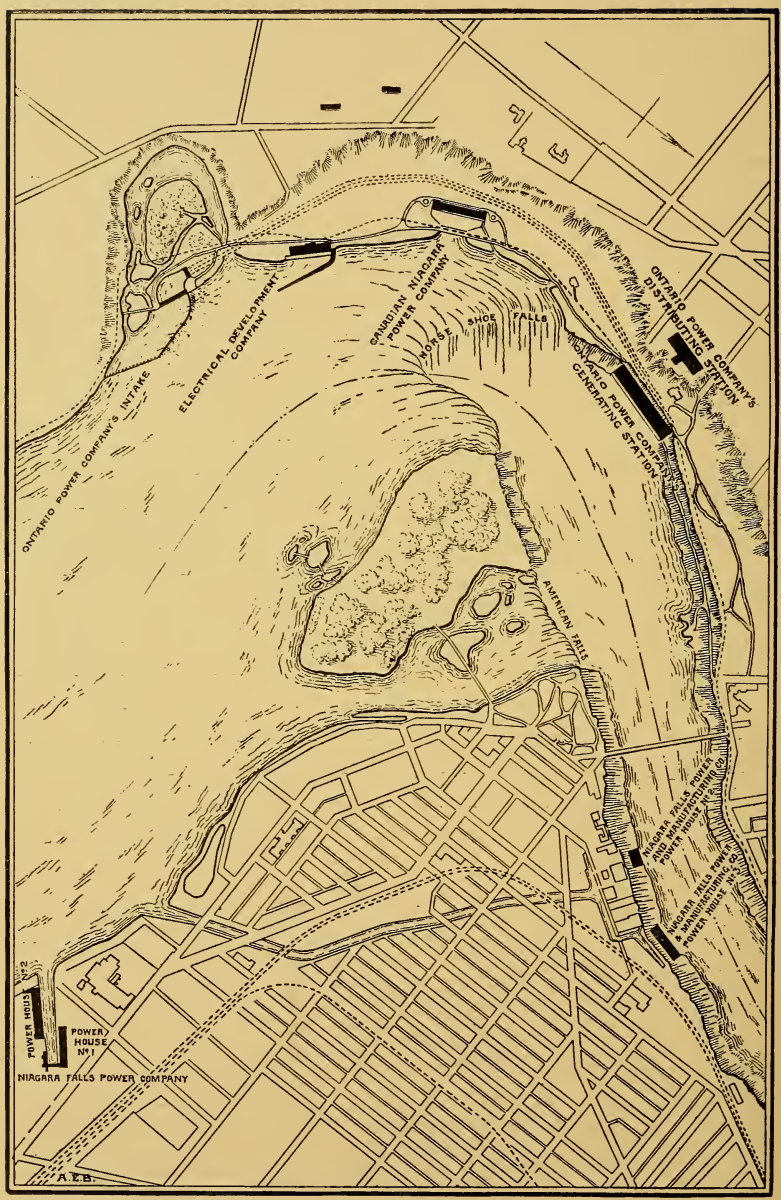

ONTARIO POWER COMPANY'S INTAKE
ELECTRICAL DEVELOPMENT COMPANY
CANADIAN NIAGARA POWER COMPANY
HORSE SHOE FALLS
ONTARIO POWER COMPANY'S GENERATING STATION
ONTARIO POWER COMPANY'S DISTRIBUTING STATION
AMERICAN FALLS
NIAGARA FALLS POWER AND MANUFACTURING POWER HOUSE No. 2
NIAGARA FALLS POWER & MANUFACTURING POWER HOUSE No. 3
POWER HOUSE No. 2
POWER HOUSE No. 1
NIAGARA FALLS POWER COMPANY
A.L.B.

Fig. 139.

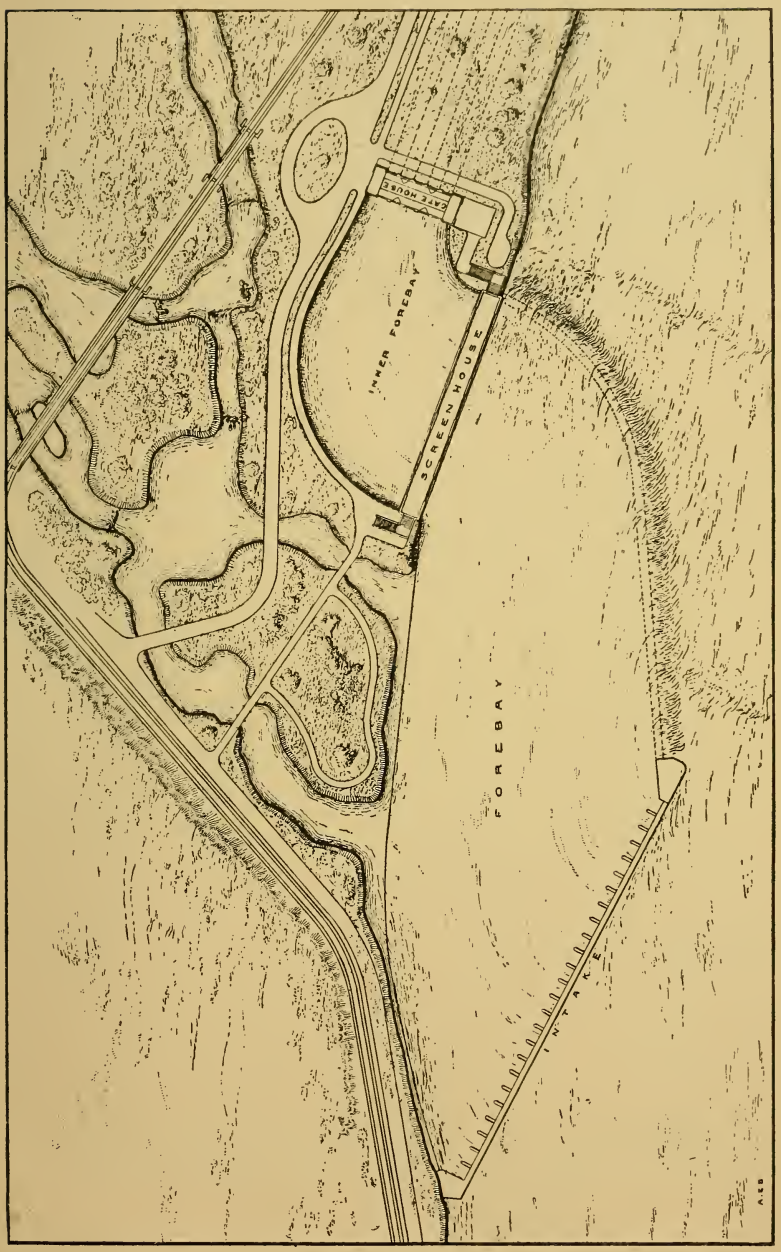


FIG. 140.

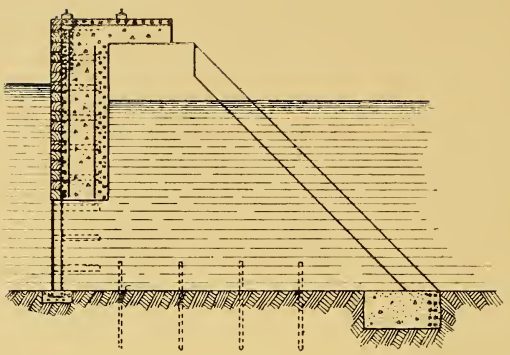


FIG. 141.

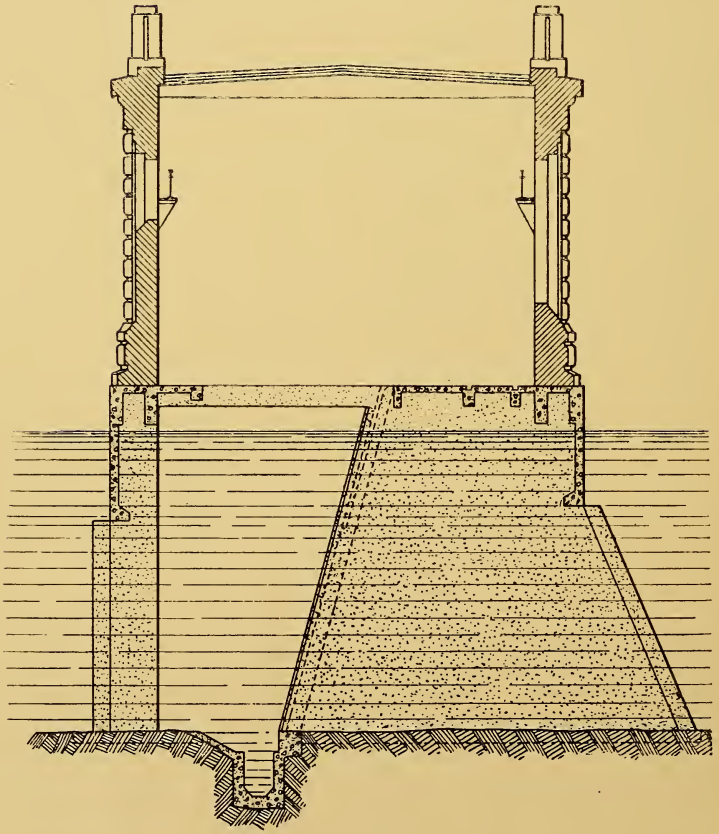


FIG. 142.

which is secured from the face of the screen by the flow of the stream. An exterior view of the screenhouse is shown in Fig. 143,

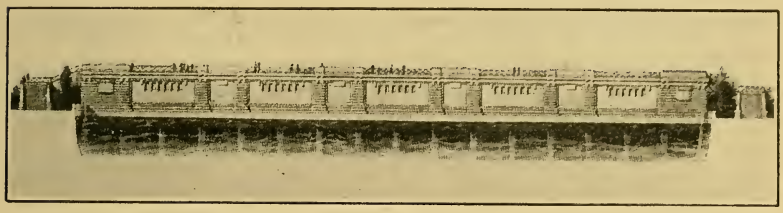


FIG. 143.

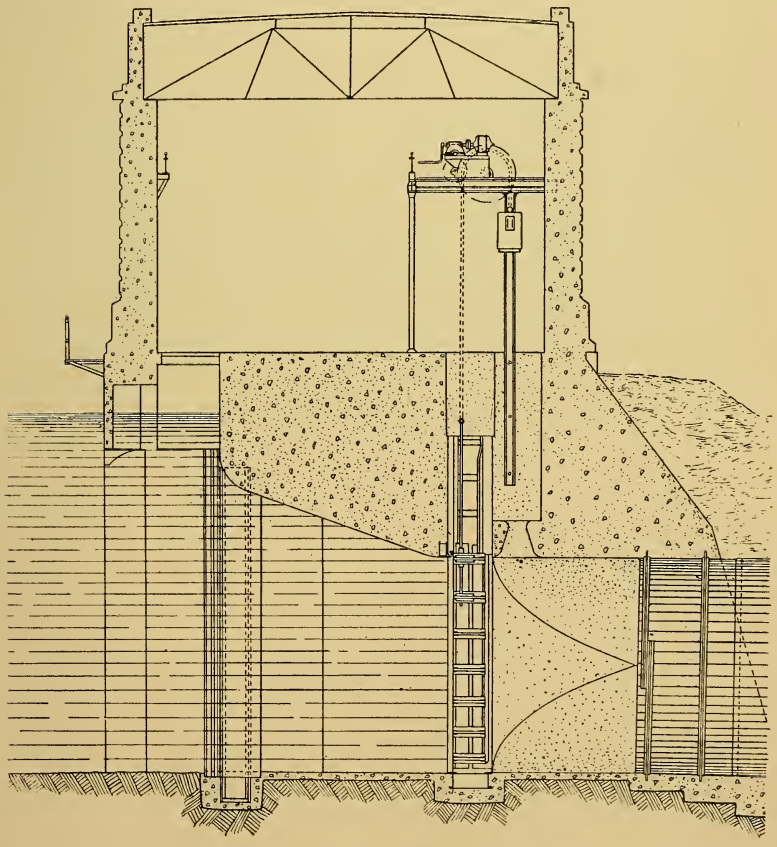


FIG. 144.

built in concrete. A section through the gatehouse is shown in Fig. 144. Here the water is 30 feet deep. Tapering portals lead to electrically operated headgates, at the mouths of which wide mesh screens are fixed. An exterior view of this building, also in concrete, is shown in Fig. 145. Both buildings are steam heated, supplied by an underground boiler plant fixed in the common abutment.

The water has thus to pass in succession three steps, each excluding surface water and floating ice and through two screens.

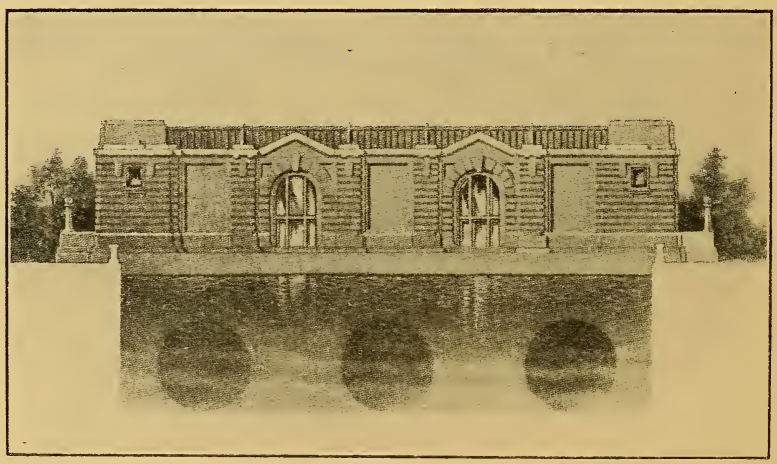


Fig. 145.

Electric cranes are provided for lifting the screens for cleaning and changing.

The main conduits 18 feet and 20 feet in diameter are of 0·5 inch rivetted and reinforced steel plate imbedded in concrete.

The velocity of flow is about 15 feet per second.

The conduit is provided at its end with a helical spillway which is really an elevated end of the main fitted with an adjustable weir and discharge tunnel. The object of this is to prevent water hammer in the event of a sudden loss of load.

Beneath the top of the cliff, and situated in a long, underground chamber, the arched roof of which supports the conduits, 9-feet diameter branches pass from the conduit through

electrically operated gate-valves controlled from the power house to the penstocks, each of which supplies water to its turbine with a velocity of 10 feet per second.

Each penstock has a massive thrust anchorage in the power house foundations, two expansion joints, an automatic relief valve, and a stone catch discharging into the river.

A section through the power house is shown in Fig. 146. This is 76 feet wide, and, when completed, will be 1000 feet in length, with the engine-room floor level 26 feet above mean water level. A plan of this power house and the high level distributing station is shown in Fig. 147. The turbines and generator are arranged in single line, and the space between them and the rear wall is occupied by a gallery carrying the row of oil pressure governors, each over the end bearing of its corresponding turbine. On this gallery the engineer has the motor-driven rheostats and the exciters, and a switchboard giving him electrical control of the penstock valves, and also control of the turbine speeds and excitation. He also has a clear view of all the machines.

Horizontal turbines are used so that all moving parts are in full view, and by the removal of a single ring the guides are exposed for cleaning and renewal. The balanced twin turbines are of the inward flow type, central discharge, mounted on 24-inch shafts with 78-inch cast-steel runners, developing 12,000 H.P. the set, under 175-feet head, 20 feet of which is due to the 10-feet diameter draft tubes. The housings are of reinforced steel plate.

The bearings are self-oiling, fitted with water-cooling system, and with a pipe system for the changing of oil, so arranged that in emergency a forced lubricator can be utilized, etc.

Very High Falls.—Fig. 148 shows a 900-H.P. Pelton wheel designed for the Kartari Falls, Nilgiri Hills, India, on a fall of 630 feet. In this case 400 R.P.M. had to be adopted for electrical reasons, and the turbine had to be designed accordingly. The supply pipe is 24 inches in diameter. The wheel is of the tangential type, with a single round nozzle, the area of which is diminished as the load decreases by the spear-shaped rod which moves in and out of the nozzle as the load falls or rises.

The nozzle is of a steel alloy, and the spear rod of Delta metal with a phosphor bronze end. The wheel centre is of cast steel,

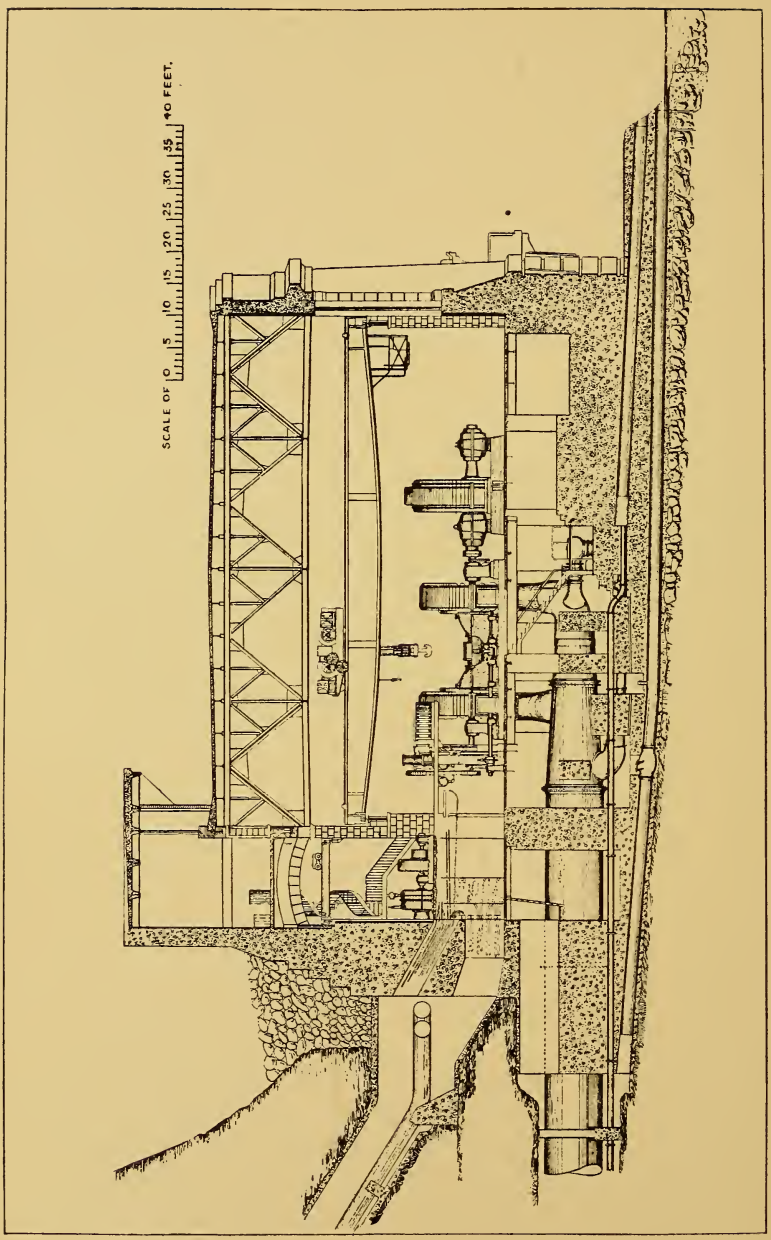


FIG. 146.

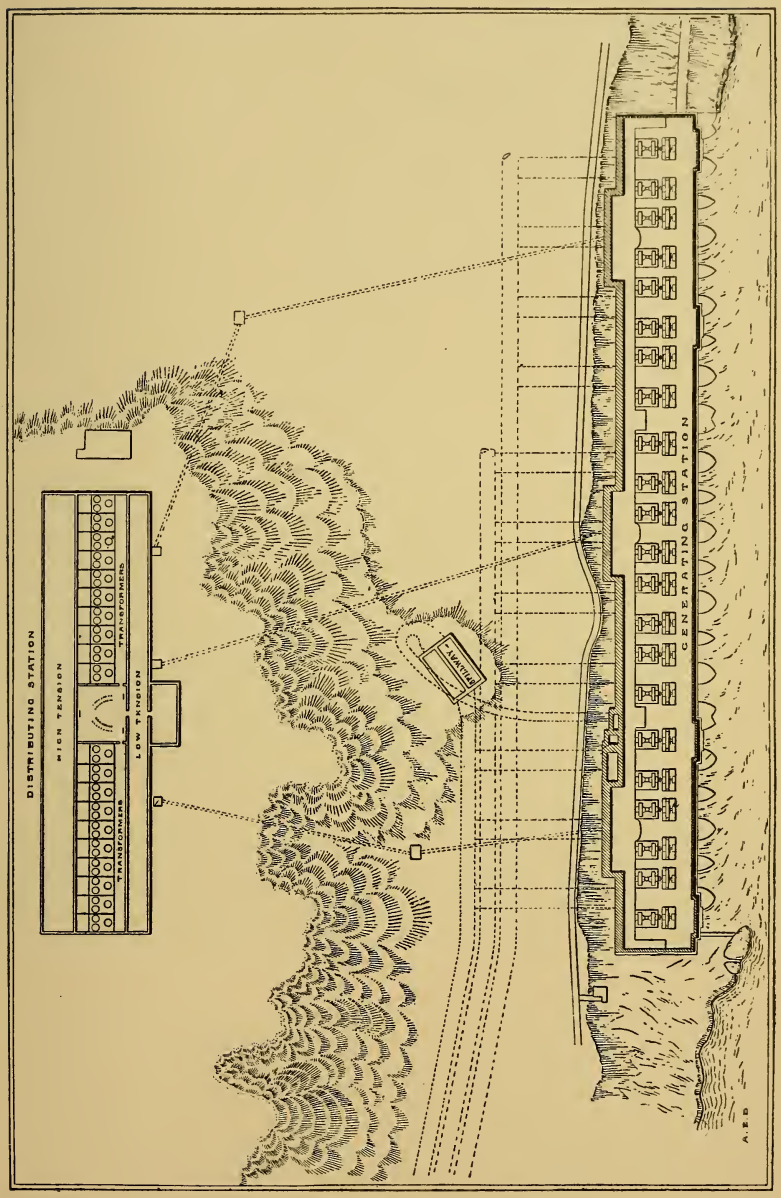

DISTRIBUTING STATION
HIGH TENSION
TRANSFORMERS
LOW TENSION
TRANSFORMERS
GENERATING STATION
CANAL
A.E.B.

FIG. 147.

and the buckets of steel alloy, bolted on separately by turned bolts. The wheel measured to the point of impact of the jet is 54 inches in diameter, and the total diameter is 5 feet. The shaft is 6½-inch diameter, self-oiling type. The moveable spear rod is worked by a hydraulic relay cylinder, or in emergency by hand.

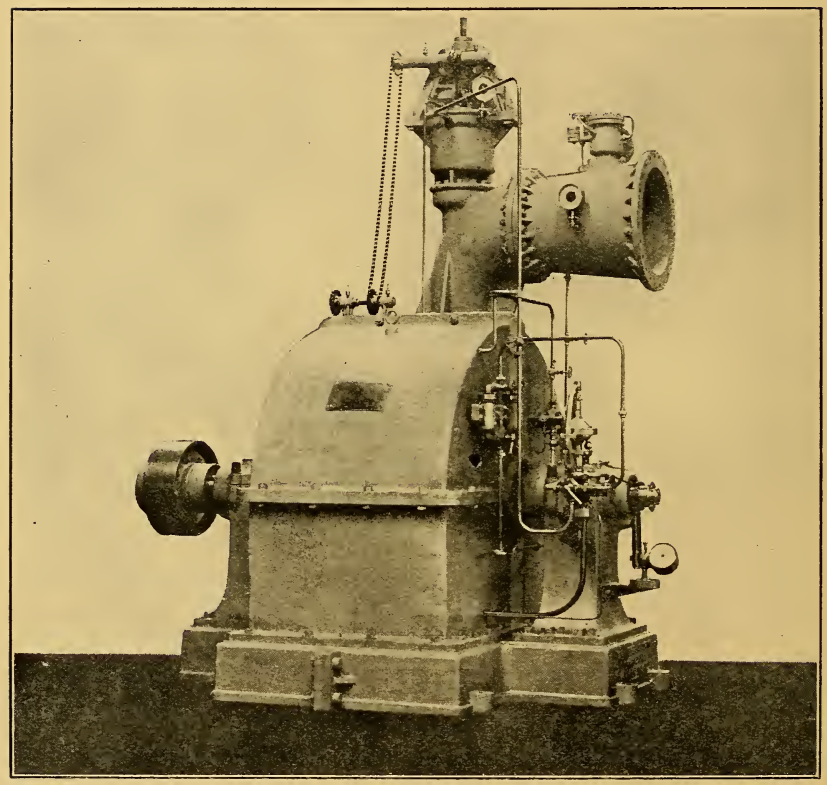


Fig. 148.

The governor is also of the hydraulic type, driven by chain gear from the turbine shaft. An automatic relief valve is placed in the inlet pipe so designed as to open instantaneously with a slight increase of pressure, and to close down slowly, and also to obviate any surging of the pressure caused by the spring loaded relief valves.

An excellent paper on "Tangential Water Wheel Efficiencies,"

by Mr. G. H. Henry, Jun., read before the Pacific Coast Electric Transmission Association, in 1903, may be referred to by those who desire to know further about the relative advantages of different shapes of buckets. This is more a matter of turbine design than germane to power house design.

Great Western Company, California.—Another power station is shown in Fig. 149 where an available head of 450 feet is utilized and vertical turbines in large units are installed. In this case a concrete lined tunnel no less than 5000 yards in length, with a flow of 2500 feet per second, has been driven to a point above the power house, where steel-pipe feeders 450 feet in length convey the water to the turbines.

In the river from which the supply is taken there is a cylindrical concrete intake tower built on rock bottom, and designed with buttresses and guides for racks with openings at four levels provided with gates, as shown in Fig. 150. Cranes are provided to operate both screens and gates, the latter being operated electrically. Clean water is thus available. The tunnel is lined with 21-inch concrete with a grade of 1 in 3000, 220 square feet in section and designed for a maximum pressure of 87 lbs. per square inch. The steel-pipe feeders from the tunnel to the turbines are constructed of steel plate varying from $\frac{1}{2}$ inch to 1 inch, with an inside diameter of 16 feet 9 inches tapering to 6 feet. A surge pipe 9 feet in diameter, 300 feet long, is fixed and empties into a spillway.

The penstocks are 5 feet in diameter and 0·68 inch in thickness with air and butterfly valves at the top of the penstock. The butterfly valves are operated by hand and the gate valves by motors controlled, as usual, from the switchboard.

The power house is a steel frame building with concrete panels 71 feet wide by 184 feet long, and is shown in Fig. 149.

It is erected on massive concrete foundations and arranged with basements to take the turbines, step bearing, pumps, and accumulators. A 50-ton electric crane is fixed in the generator room. The power house contains four 18,000-H.P. reaction turbines and two 500 H.P. impulse wheels coupled respectively to 10,000-K.V.A. 3-phase generators, 11,000 volts, 60 cycles, and 250-K.W., 250-volt direct current generators. The 18,000-H.P. reaction

turbines are of the vertical inward-flow type, 400 R.P.M., operating under a head of 425 feet—a high figure for turbines of this

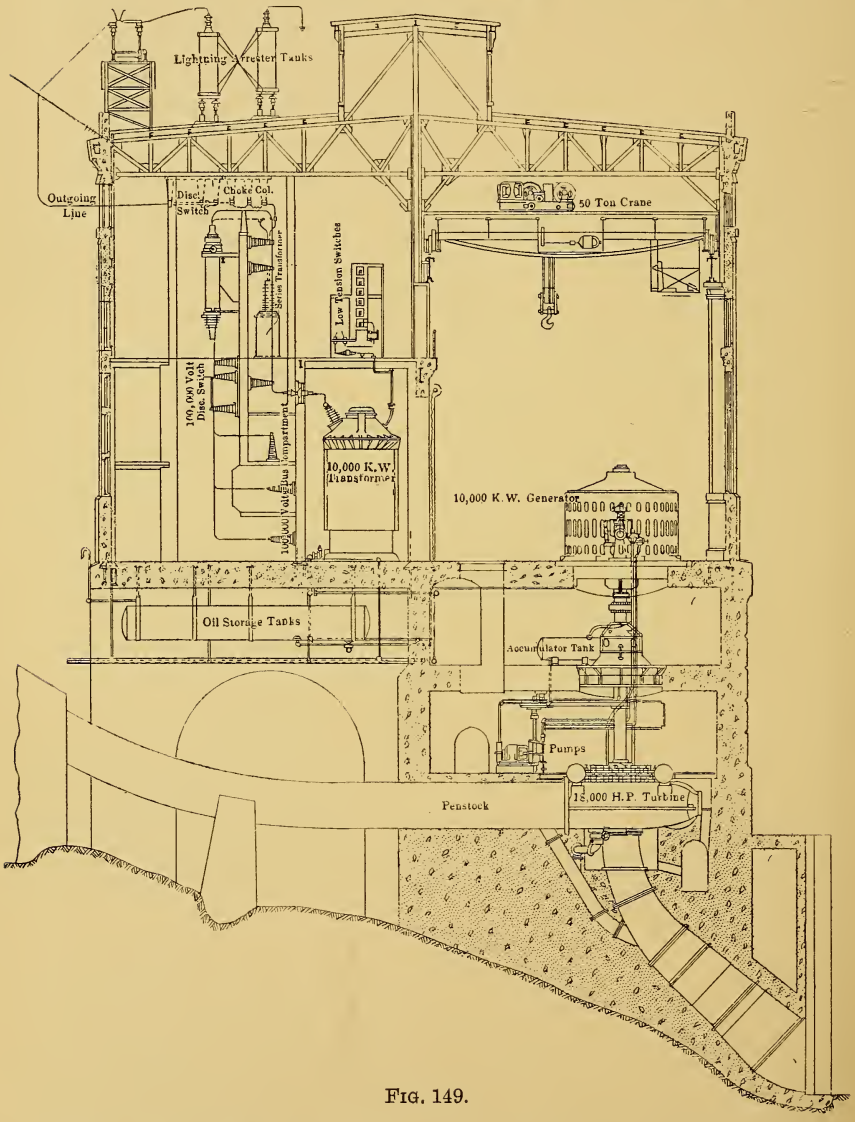


FIG. 149.

class. The casing is of cast steel, the runner of bronze, cast steel 9-inch vanes, and vie disc, thrust bearings which carry a

total weight of 65 tons supplied with oil at a pressure of 250 lbs. per square inch.

The guaranteed over-all efficiencies were—

Full load 80 per cent.
$\frac{3}{4}$ „ 82 „
$\frac{1}{2}$ „ 76 „

Guanajuato, Mexico.—Another typical hydro-electric power house, whence energy is transmitted a distance of 101 miles at

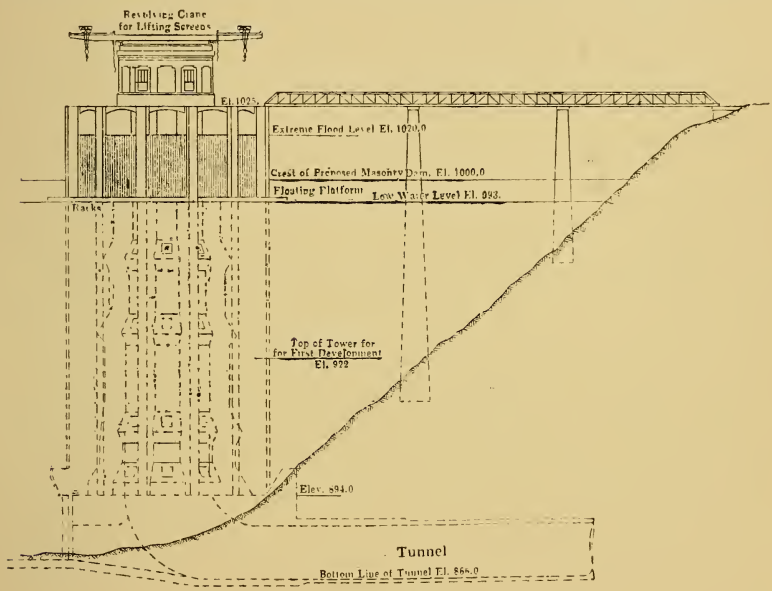

Revolving Crane for Lifting Screens
El. 1025
Extreme Flood Level El. 1020.0
Crest of Proposed Masonry Dam, El. 1000.0
Floating Platform
Low Water Level El. 993.
Racks
Top of Tower for for First Development El. 972
Elev. 934.0
Tunnel
Bottom Line of Tunnel El. 868.0

FIG. 150.

a pressure of 60 kilovolts. The area of the watershed is 400 square miles with an elevation varying from 6000 to 12,000 feet above sea level.

The curved masonry dam for directing the water to the head race is built from local erupted rock, partly laid in lime mortar and faced with masonry set in cement, and is 90 yards long. Water is admitted through four head gates with a maximum flow of 2·6 feet per second. The head race or canal is 7300 yards in length, 13 feet wide at the bottom, and 7 feet deep. The side slopes are: 1 : 1 in soft earth, 1 : 2 in hard rock, and 1 : 5 where

masonry lined. The grade is a uniform 1 : 2500, and the capacity 280 cubic feet per second. A spillway and a settling basin are provided, as well as a small storage reservoir. The pipe line is 1100 yards long, and varies in diameter and thickness as follows :

	Inside diameter. inches.	Thickness of steel plate. inches.
1100 feet	69	$\frac{5}{16}$
1100 ,,	63	$\frac{3}{8}$
450 ,,	57	$\frac{7}{16}$
350 ,,	57	$\frac{1}{2}$
200 ,,	57	$\frac{9}{16}$
200 ,,	57	$\frac{5}{8}$

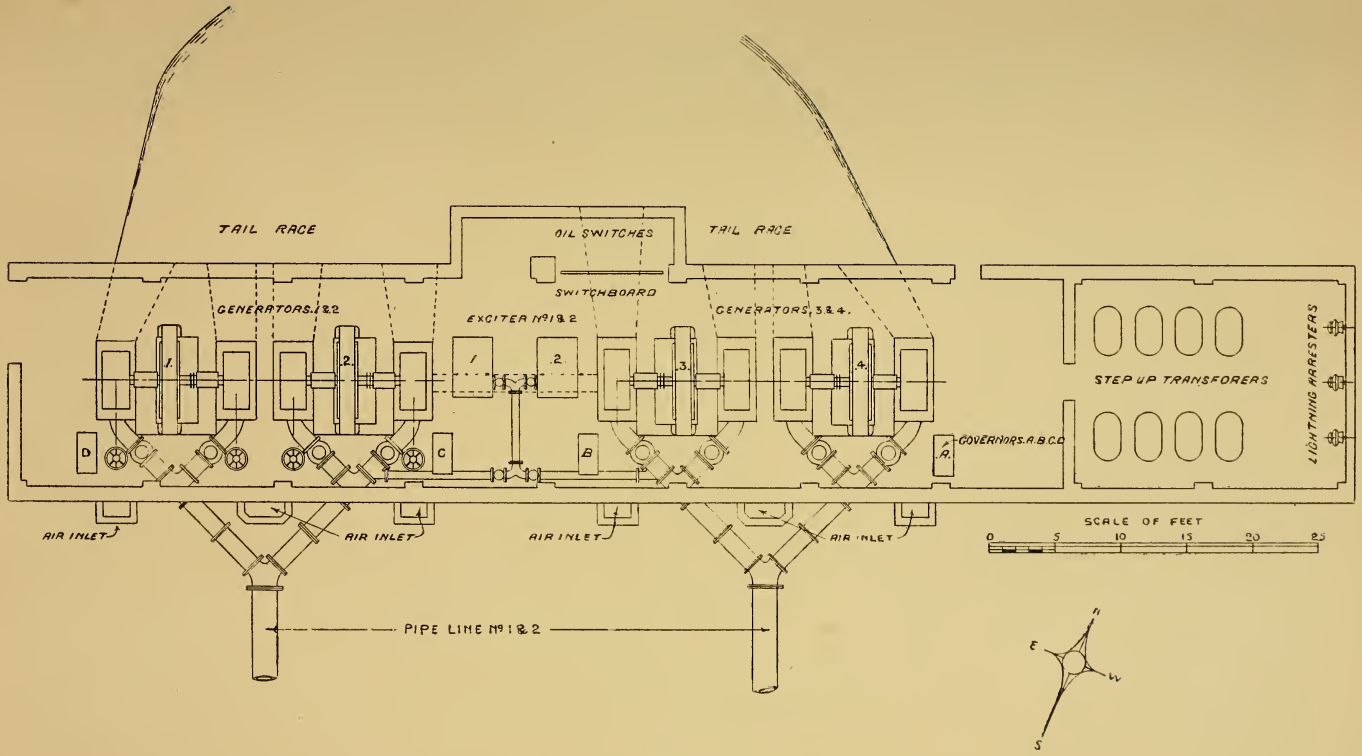
The steel was specified to have a tensile strength of 24 to 28 tons per square inch, with an elastic limit of one half these figures, and a minimum elongation of 25 per cent.

The longitudinal seams are double rivetted, and the circular seams single rivetted.

The power house is built of local volcanic stone, and the roof of galvanized iron, lined with an anti-condensation lining on steel principals. The dimensions of the power house are 200 feet long by 32 feet wide, supplied with two ten-ton cranes. A plan is shown in Fig. 151, and a cross-section in Fig. 152.

The Cauvery Falls power house in Southern India contains 6–1000 H.P. turbo generators, the effective head being 382 feet. Each turbine being capable of developing 1250 B.H.P. at this head, with 2220 cubic feet per minute. The wheels are 60 inches diameter with a guaranteed efficiency of 75 per cent. at full gate and 70 per cent. for half gate. The governors maintain normal speed within 2 per cent. and sudden 10 per cent. variations of load, 4 per cent. for sudden 25 per cent. variations and within 8 per cent. for sudden 50 per cent. variations. The governors are also fitted with pressure regulators to keep the pressure in the pipe lines constant within 5 per cent. of normal under sudden variations of load.

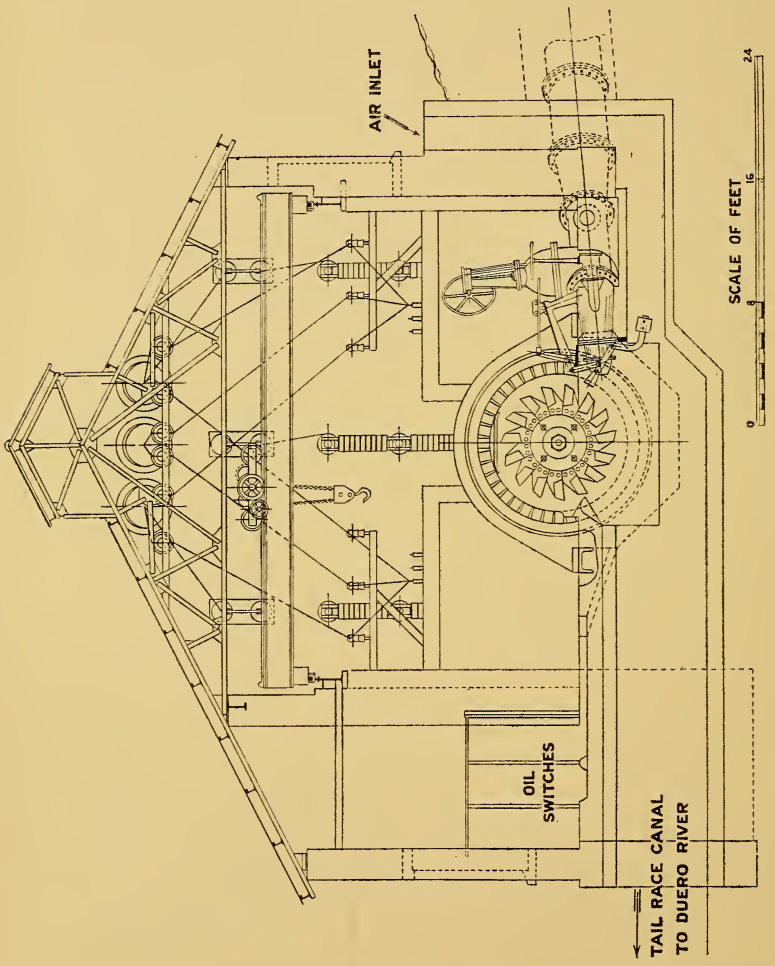
The turbines are supplied by three penstocks, which convey the water from the forebay to the power house nearly 400 feet below. These pipes are 45 inches in diameter at the upper end tapering to 36 inches at the lower end, and are made of steel plate $\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick, and are carried on masonry pins 15 feet apart. They are fitted with expansion joint and three


TAIL RACE
OIL SWITCHES
TAIL RACE
SWITCHBOARD
GENERATORS, 1&2
EXCITER Nº1&2
GENERATORS, 3&4.
STEP UP TRANSFORERS
LIGHTNING ARRESTERS
GOVERNORS A.B.C.D
AIR INLET
AIR INLET
AIR INLET
AIR INLET
SCALE OF FEET
0 5 10 15 20 25
PIPE LINE Nº1&2
N
E
W
S

Plan.

FIG. 151.

anchorages on the hill slope. On entering the power house each penstock bifurcates and serves two wheels. There are two low level dams, one for diverting the dry season discharge into one of



Elevation.

FIG. 152.

the streams, and the other to divert the water into a canal leading to the sluice gates.

The head sluice or intake is about 2 miles above the Falls, and contains 8 gates, 4·5 feet by 5 feet, four in each channel and flanked by a scouring sluice. The two channels are $3\frac{1}{3}$ miles long,

divided by an earth bank 26 feet wide at base and 10 feet wide at crest.

The gradient in the earth channel is one-third that in the rock sections. They are 18 feet and 12 feet wide respectively, and masonry-lined with slopes 1 : 1, and the earth slopes are 45 per cent. The normal depth of water is 5 feet, and the rated discharge 15,000 cubic feet per minute. Spillways are provided for floods. The channels deliver into a forebay, whence the penstocks are supplied with a double geared gate and chamber containing the valve controlling each pipe line.

The total cost of this plant was approximately

Hydraulic plant £26,500 . . .	£4·4	per H.P.
Electrical plant £30,000 . . .	5·0	„
£56,500	9·4	„

or £12·5 per K.W. installed.

Pressure Turbines.—In pressure or reaction turbines the buckets must be completely filled with water. This is the cheapest type of turbine, and it is only affected by backwater to the extent that the water level is increased, and it can be placed above the tail race with a draft tube so that part of the head is obtained from the suction on this tube. The runner must be supplied with water all over its circumference, otherwise if it is submerged the buckets after moving away from the fixed guide blades will be full of still water which has to be displaced when the buckets come round again, so that power has to be wasted in moving this dead water around with the wheel. If not submerged then water is used in filling the buckets, which have emptied on leaving the guide blades, before the full head can be utilized.

Table No. CXII. gives the leading particulars and approximate prices of horizontal turbines.

Pelton Wheels.—This is a very simple turbine used on high falls in which the diameter can be increased without decreasing its efficiency. A jet of water issues from a nozzle and impinges on the buckets. The nozzles can be easily replaced if scored by silt and grit. Efficiencies of 80 per cent. can be obtained.

When the speed of a Pelton wheel of the diameter necessary for the power required and supplied by a single jet is too slow for

the generators a higher speed can be obtained by using a smaller wheel with two jets as shown in Fig. 153, and will of course give

TABLE CXII.

B.H.P.	Fall in feet. / Fall in metres.	50 / 15·25	80 / 24·4	100 / 30·5	120 / 36·57	150 / 45·72	180 / 54·86
250	R.P.M. . . .	460	600	665	720	720	720
	Cubic ft. per min.	3530	2206	1765	1470	1175	980
	Weight (t. & cwts.)	4·16	4·4	4·1	4·0	3·16	3·10
	Approx. price .	£295	£255	£245	£240	£225	£210
500	R.P.M. . . .	300	488	500	500	500	600
	Cubic ft. per min.	7060	4412	3530	2940	2350	1960
	Weight (t. & cwts.)	8·16	8·0	7·1	6·0	5·5	4·10
	Approx. price .	£410	£370	£345	£300	£290	£280
1000	R.P.M. . . .	230	333	428	428	428	428
	Cubic ft. per min.	14120	8825	7060	5880	4710	3920
	Weight (t. & cwts.)	13·8	12·9	10·14	9·18	9·6	8·4
	Approx. price .	£530	£505	£485	£460	£445	£420
1500	R.P.M. . . .	187	273	333	375	400	400
	Cubic ft. per min.	8300	13300	10600	8820	7060	5880
	Weight (t. & cwts.)	24·0	22·2	21·0	19·2	17·14	16·0
	Approx. price .	£860	£815	£785	£755	£715	£670

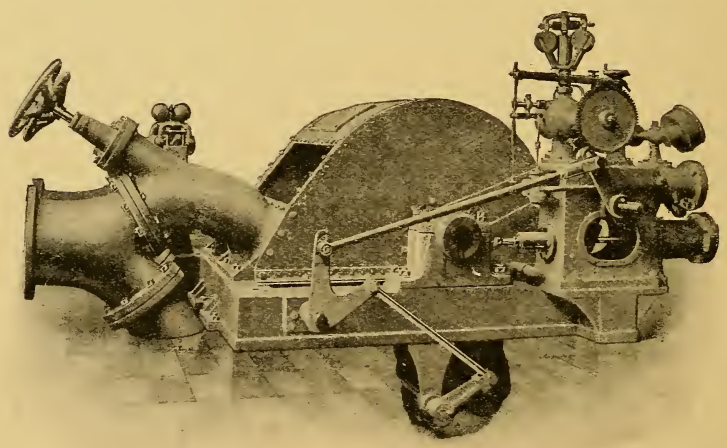


FIG. 153.

nearly twice the power. Two or more wheels on one shaft, one to each jet, are preferable, however, and more efficient.

These wheels are specially made in small pieces so as to enable them to be transported easily by mules. Some makers of turbines think that it is undesirable to use more than one jet per wheel, though they are designed for two and sometimes even three jets. In the case of vertical shaft wheels four jets may even be used. The shape of the bucket is obviously a matter of importance and affects efficiency. The peripheral velocity of such wheels is approximately $0{\cdot}45\ \sqrt{2gH}$. There is another relation which must be carefully attended to and that is the relative diameter of the water jet and that of the wheel. For high efficiencies this is given as $\frac{1}{15}$th.

There are several designs of pressure regulators, an essential apparatus to limit the rise of pressure in pipes when the turbine is suddenly shut off. There is greater difficulty about this the greater the head on the pipe line. The best method is to operate a deflector by means of a water ram and also to operate the needle in the jet as devised by Böving. This pressure regulator is connected to the automatic governor which is responsible for all the overtaking work.

Table No. CXIII. gives the leading particulars of typical Pelton wheels.

TABLE CXIII.

Diameter of wheel. Inches.	Fall in feet. / Fall in metres.	250 / 76·19	300 / 91·43	350 / 106·6	400 / 121·9	500 / 152·3	600 / 182·8	700 / 213·3
72	B.H.P.	265	350	440	535	760	980	1250
	R.P.M.	197	217	234	250	279	306	330
	Cubic feet per min.	747	822	889	941	1064	1147	1250
	Weight tons	4·75	4·75	4·75	4·75	4·73	4·75	4·75
	Approximate cost £	245	245	245	245	245	245	245
60	B.H.P.	184	240	305	375	525	675	850
	R.P.M.	237	261	281	301	336	368	396
	Cubic feet per min.	519	564	616	660	735	790	850
	Weight tons	4	4	4	4	4	4	4
	Approximate cost £	200	200	200	200	200	200	200
48	B.H.P.	119	155	195	235	330	440	550
	R.P.M.	296	325	351	375	420	460	496
	Cubic feet per min.	336	364	394	414	462	515	550
	Weight tons	3·1	3·1	3·1	3·1	3·1	3·1	3·1
	Approximate cost £	170	170	170	170	170	170	170

Check on Turbine Consumption.—A check upon water consumption in power plants is very necessary in many cases, as water supply is not unlimited, and the extra cost of impounding is a consideration in the capital outlay.

In many new plants Venturi "throats" can be inserted and an accurate check taken; in existing plants this cannot be so easily done. A Pitot tube which rates the nozzles in existing turbines can be utilized in these cases, and reference can be made to the able paper by Mr. W. R. Eckhart read before the Institute of Mechanical Engineers, 1910.

Summary.—The above notes are necessarily very short, and describe only a few leading types of power house for hydro-electric systems. To discuss the different varieties possible would require a treatise by itself, and the Author would refer designers to such standard works as Water Turbine Plant by Jens Orten-Böving and other authors, wherein fuller information can be obtained.

The designer not only has to settle the important data as to amount of water available, available net head, amount of storage, cost of works, position and construction of dam, and auxiliary details, but also the best type of turbine to adopt. If the system comes under the classification of low falls, then the various types of turbine available are many in number, and require the more careful consideration so as to utilize the highest net head, and thus to obtain the highest efficiency.

It must be added that in determining the economic considerations of water utilization, one must also consider (in this case as an integral part of the generating plant) the capital cost of the transmission line and its annual maintenance.

CHAPTER X

SWITCHGEAR

It is a comparatively easy matter to lay out the mechanical arrangement in a power house in a simple and straightforward manner. Given adequate attention to the pipe arrangements this general design does not offer any great difficulties to the initiated ; but it is when one comes to the switching details that not infrequently one finds an apparently careless arrangement, with undue complexity and a disregard of the unfortunate engineers who have to control and run the power house subsequently. The switchgear is really the nerve centre of the system, and not only must it be capable of adequate control of the generators and the feeders or transmission lines as well for ordinary working as for emergencies, with a due regard also for further extensions and developments of the system, but it requires also to be simple in character, as free as is humanly possible from risks of fire, short circuits, "earths," and lightning strokes, but also safe in operation to the attendant, and for inspection and cleaning.

Essentials in Switchboard Design.—The designer must bear in mind the following essentials in a good switchboard lay out.

(*a*) Simplicity, with a due regard to adequate protection, is a mark of good design.

(*b*) All parts should be readily accessible, but high pressure parts accessible only to authorized persons.

(*c*) The instruments, switch parts, straps, plugs, relays, etc., should be (as far as practicable) standards and interchangeable.

(*d*) The whole of the switchboard should be fire proof, *i.e.* bare connections wherever possible, and not india-rubber covered cables unless run in steel conduit. For potential leads, etc., where insulation is necessary and conduit not used, then fireproof coverings should be used.

(*e*) The conductors, switch contacts, etc., must be so designed as to carry their rated currents without overheating.

(*f*) The assembly of the panels, lay out of switch cells, etc., should be symmetrical.

(*g*) A breakdown on one section of the board should not cause any dislocation in another part, and should affect only the generator, or feeder connected to it.

(*h*) So far as possible the switchgear should be "fool proof," *i.e.* wrong connections such as putting in a wrong switch should be impossible without some warning to the operator.

(*i*) The design and position of the board and the component operating panels and apparatus should allow of adequate extension along pre-arranged standard lines.

Power house switchgear will here be subdivided broadly into three classes, (*a*) alternating high pressure, (*b*) direct current medium pressure, which will also include tramways supply, and (*c*) auxiliary switch boards.

High-pressure Alternating Boards.—The following notes will refer more particularly to 3-phase switchgear. They also apply, almost entirely, to single-phase systems.

These high-pressure boards may be conveniently classed into (*a*) remote control, and (*b*) direct control. In both cases the operating board is wholly low pressure, and the high-pressure parts are screened from the operator. Taking first the remote controlled type. The oil-break switches, main bus bars, isolating links, etc., are right away from the operating panels. The latter can, therefore, be placed wherever the operator can most efficiently control the plant, and the apparatus can be placed in an annexe to the main building if desired.

The operating panels can either be of the (*a*) vertical type as shown in Fig. 176; (*b*) bench type as shown in Fig. 154, when the panels are slightly inclined (this figure shows a board made to the Author's specification for a 6600-volt 3-phase power house); or (*c*) separate pedestals, one to each generator, or transmission line as shown in Fig. 155.

The adoption of either of the two former is really a matter of choice, and partly of available space or position. Each type is applicable to moderate size power houses.

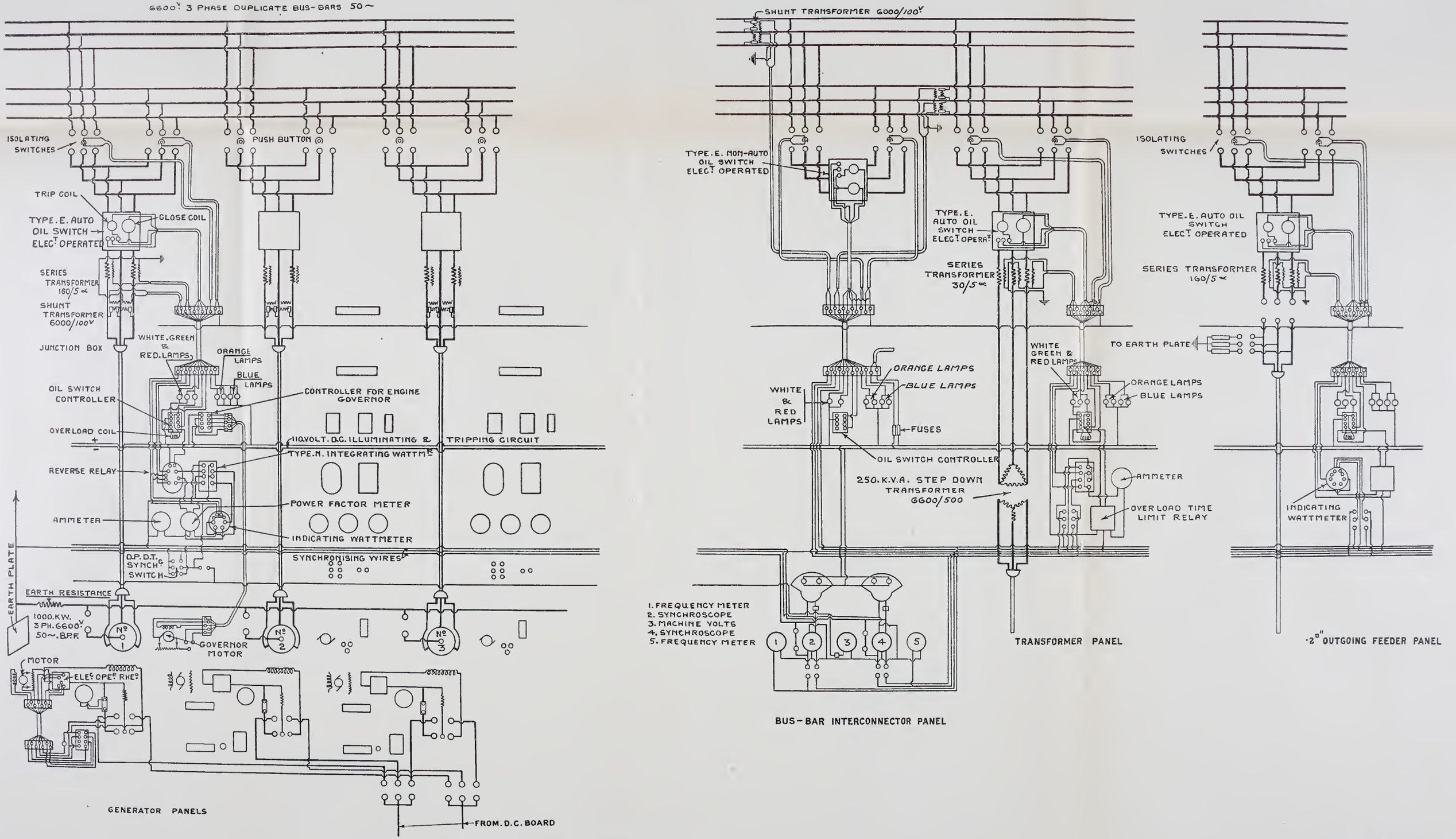


PLATE X.—DIAGRAM OF CONNECTIONS—H.T. THREE-PHASE SWITCHBOARD: BAHIA BLANCA.

[*To face page* 343.

The pedestal type has some advantages for very large units as in bulk supply stations, either steam or water driven.

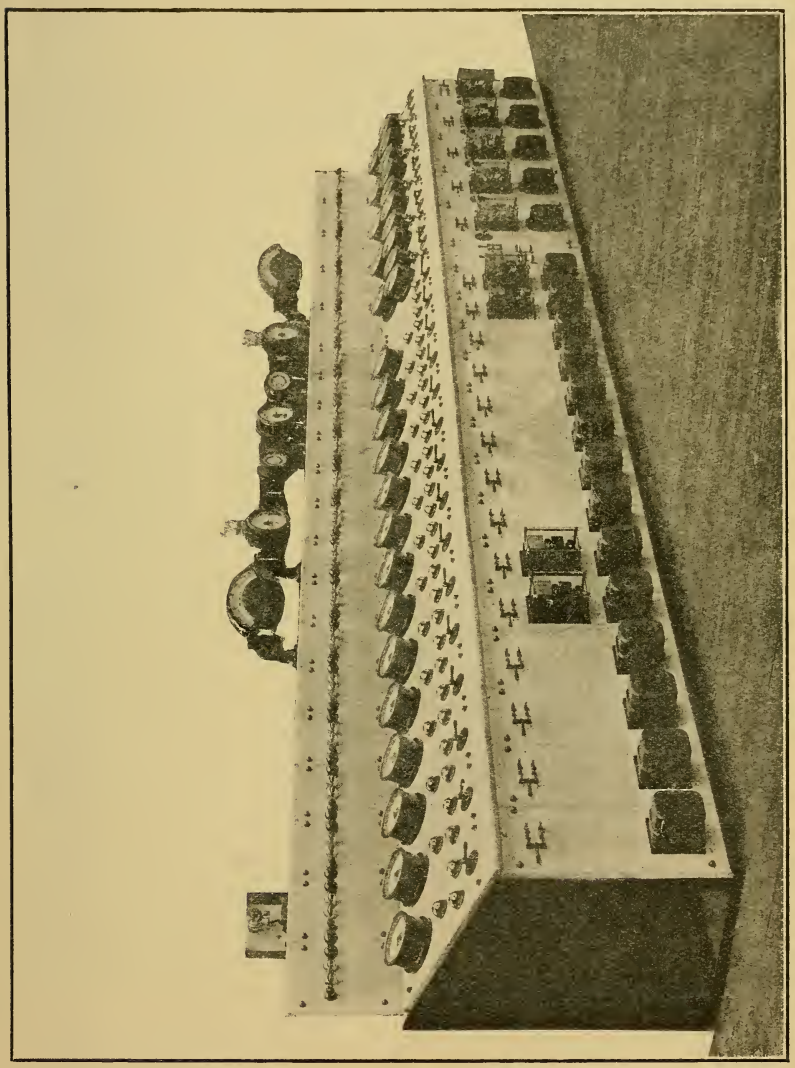


Fig. 154.

Remote Control H.T. Board.—Plate No. X. shows a typical diagram of the remote electrical control of oil-break switches. It

will be seen that automatically operated red and green lamps are provided, which show respectively whether the control switch (and therefore the oil-break switch) is closed or open. The pilot circuits

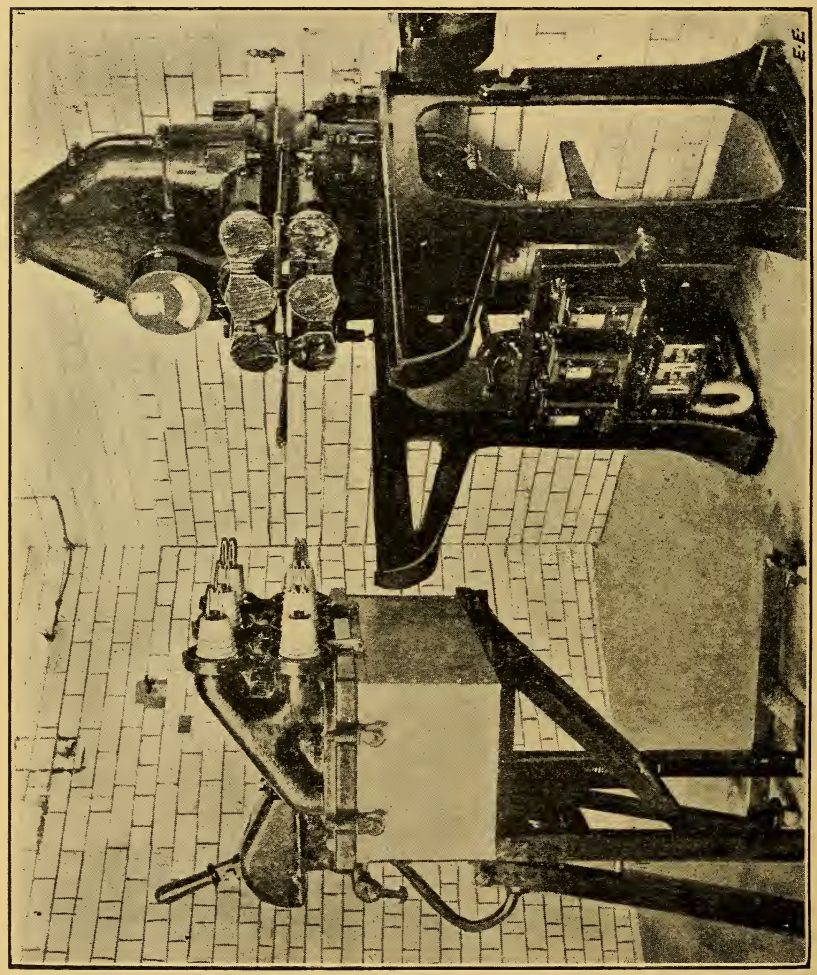


Fig. 155.

are usually worked at a pressure of 110–125 volts, supplied from a small auxiliary battery, or taken from across some of the cells of a main battery. The control switch on the operating panel thus controls the remote oil-break switch through the medium either

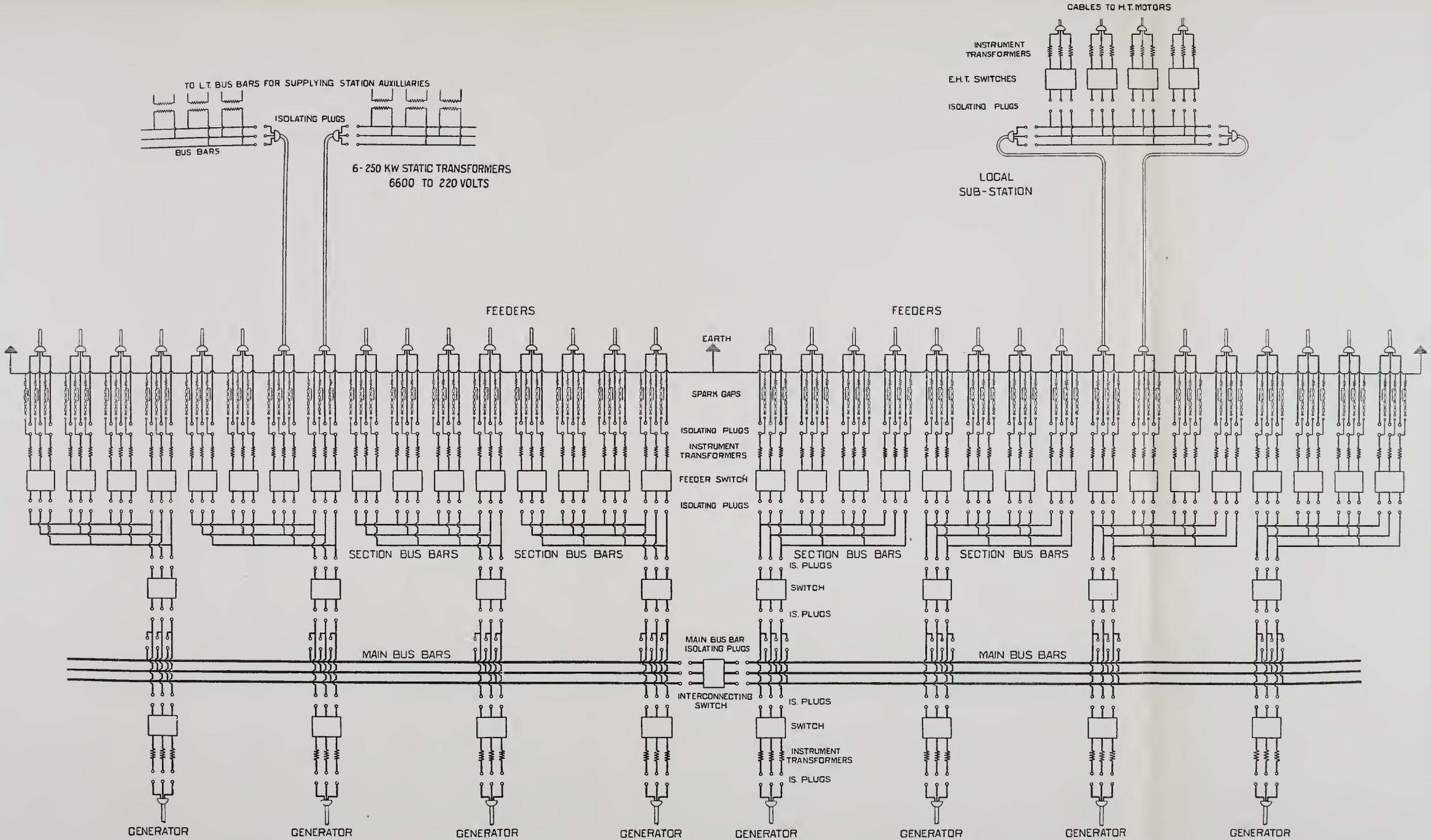


PLATE XI.—DIAGRAM OF CONNECTIONS, H.T. THREE-PHASE SWITCHBOARD, GREENWICH.

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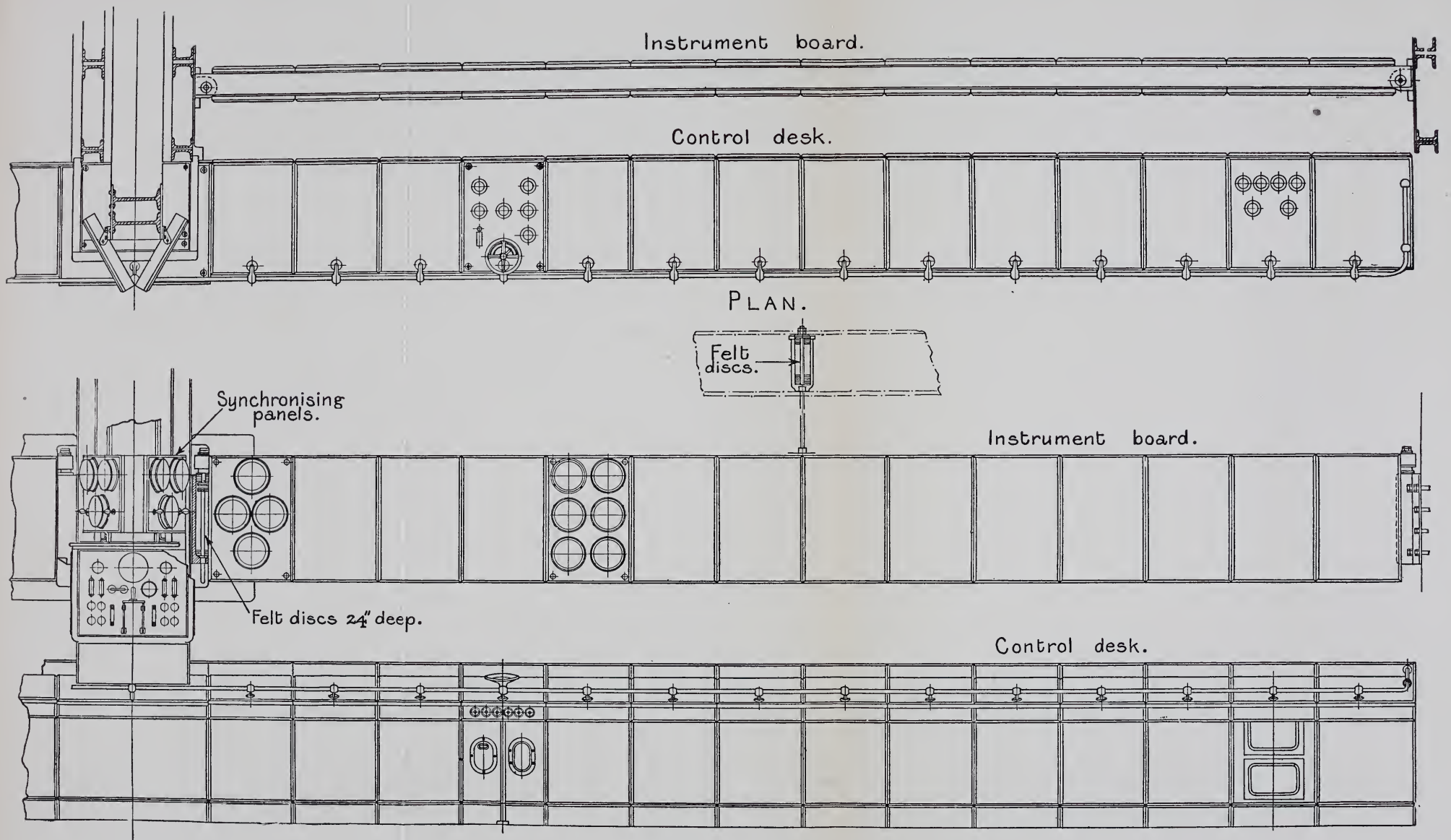


PLATE XII.—GREENWICH H.T. SWITCHBOARD.

[*To face page* 345.

of a motor, which compresses a spring on the main switch, or a powerful solenoid.

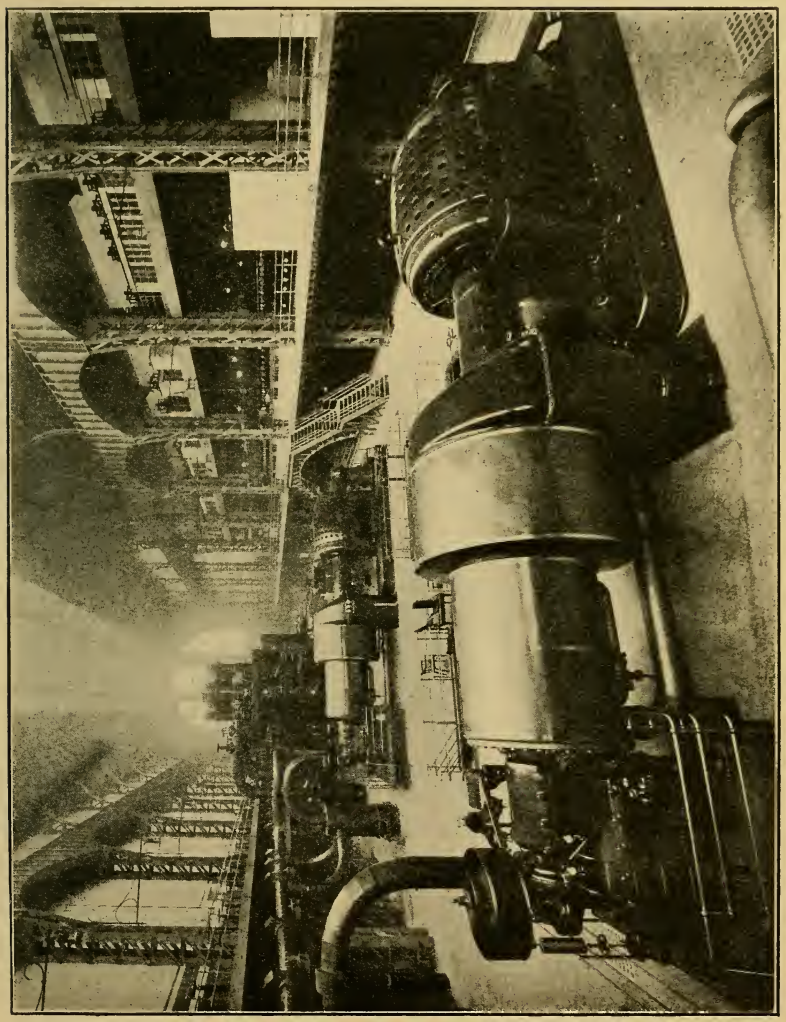


Fig. 156.

Greenwich Power House.—A typical example of a remote controlled power station switchboard is shown in Plates Nos. XI. and XII., and a general view in Fig. 156. This shows the

Westinghouse switchgear installed in the Greenwich power house. Following out the diagram shown in Plate No. XI., it will be seen that there are eight generator circuits and thirty-two feeder circuits arranged in eight sections. The total output arranged for being 34,000 K.V.A. normal rating or 42,500 K.V.A. on emergency, the maximum load being 30,000 K.W. A 3-core cable is brought from each generator to a trifurcating box, shown at the bottom of the diagram where all three separate tails are taken, each passing through its isolating link and instrument series transformer to the oil-break switch. On the other side of the switch are further links, enabling the generator switch to be isolated entirely. The connection there joins on to the main bus bar (but not directly, as is explained below), after which come further links, the sectional switch further isolating links and then the sectional bus bars.

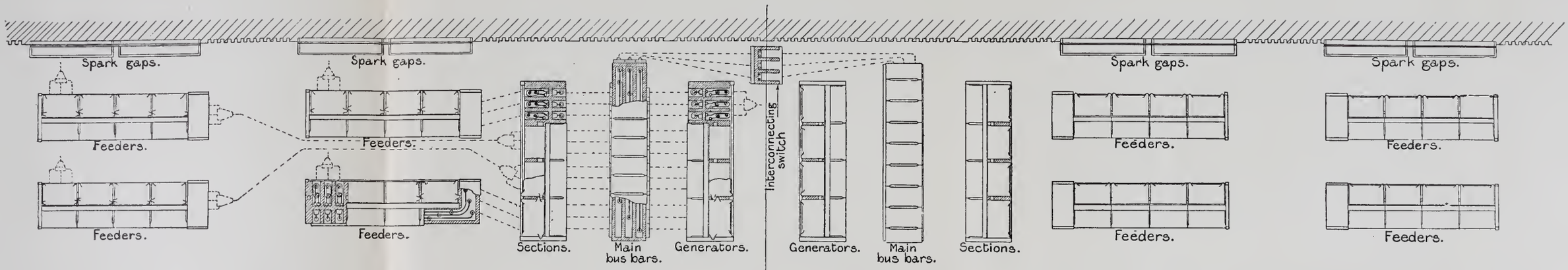
Sectional H.T. Bus Bars.—Each set of sectional bars controls four feeders. Each feeder starting from the bus bars has isolating links, feeder oil-break switch, instrument series transformers, and further isolating links, ending in a trifurcating box in which the feeder 3-core cable ends. Spark gaps are fitted, as shown in the diagram, to each phase of each feeder.

A further protection against any general breakdown will be noticed in the diagram (Plate No. XI.). Each generator line and corresponding sectional bus bar represents one complete unit. In normal working the generators and feeders are all paralleled on the main bus bars through isolating main bus-bar links. Thus, should any accident arise to the main bars, or to the synchronizing gear, each generator can be run independently of the others directly on its own sectional bars.

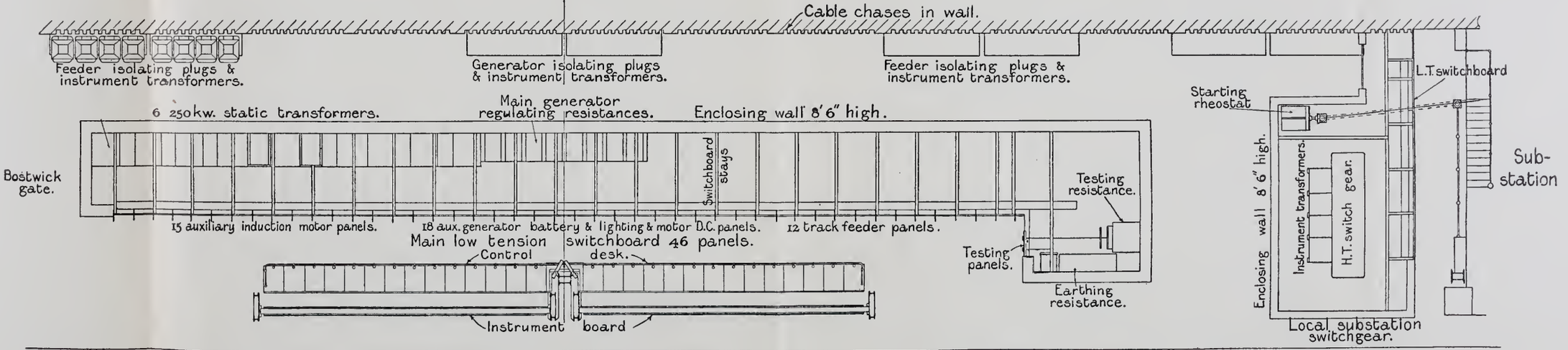
The main bars are also divided into two sections by a disconnection switch, and normally are run interconnected.

Plate No. XIII. shows plans of the lower and upper galleries respectively. The lower contains the control desks, instrument assembly boards, instrument transformers, as well as the generator and feeder isolating links, fixed on the power-house wall. The upper gallery accommodates the oil-break switches and their own isolating links, the bus bars, and the spark gaps.

Plate No. XIV. is a section through the upper and lower galleries. The control desk faces the engine-room. The isolating links are



PLAN OF TOP GALLERY.



PLAN OF LOWER GALLERY.

PLATE XIII.—GREENWICH H.T. SWITCHBOARD.

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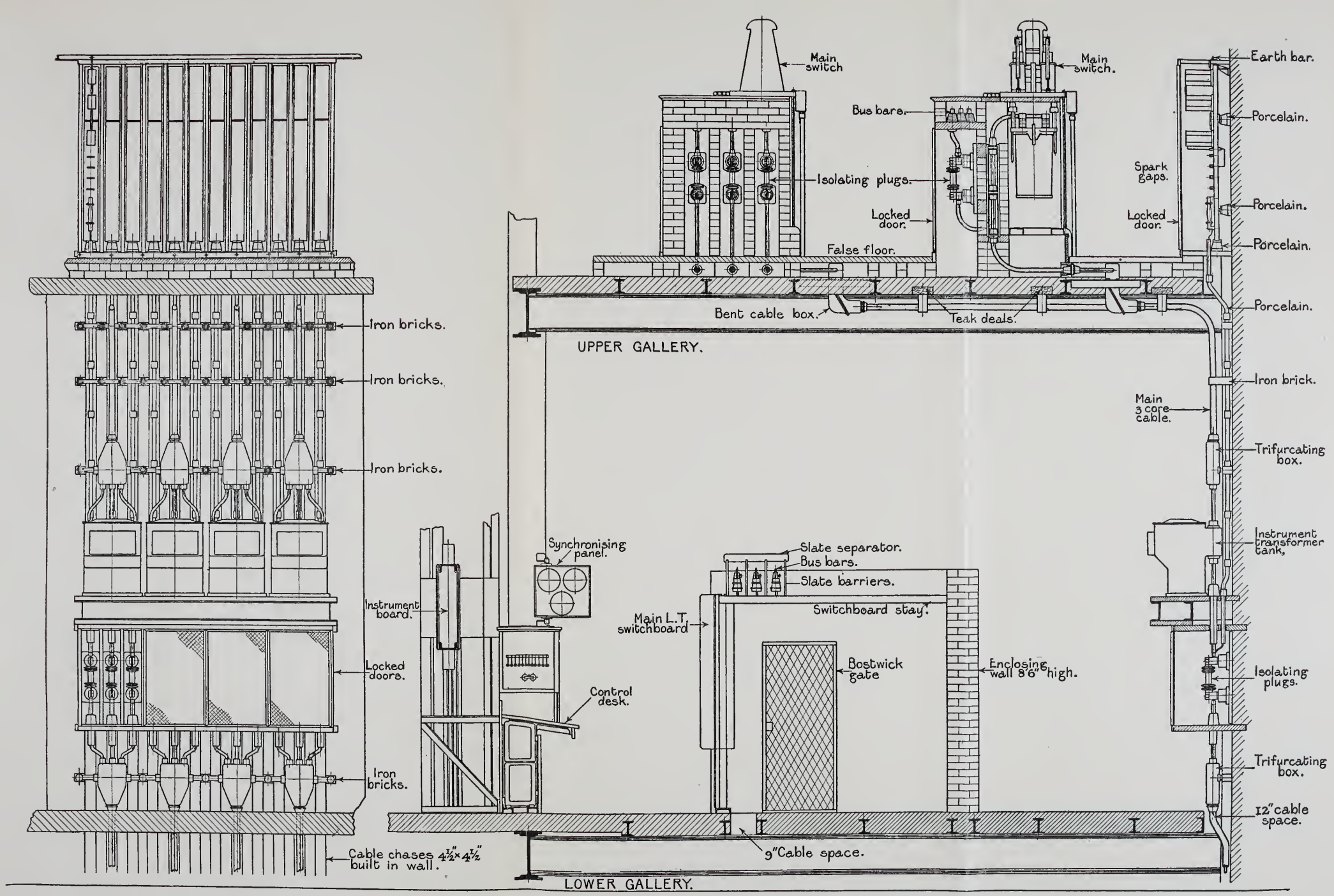


ELEVATION OF GEAR ON WALL.

SECTION THROUGH GALLERIES.

PLATE XIV.—GREENWICH H.T. SWITCHBOARD.

[*To face page* 346.

mounted upon insulators built in the power-house wall. The instrument transformers (three series and two shunts to each generator or feeder) are carried upon brackets built out from the wall. The oil-break switches are contained within glazed brick cubicles. Lead-covered 3-core cable is used wherever possible for connections between the various high-pressure parts.

Synchronizing Gear.—In addition to the synchronizing gear in the lower switch gallery, there is a synchroscope fixed near the main stop valve of each steam set and connected in parallel with the other synchronizing gear when required. The driver can thus bring his set into synchronism with the other running sets by means of his synchroscope without having to depend upon signals from the switch gallery.

Engine-room Signals.—A simple set of signals is fitted between the operating gallery and engine-rooms. Two large illuminated telegraph boards are fixed and worked from the control desk. By them the number of the machine and the signals "Slow," "Run up," "On load," "Reduce" and "Stop" are shown as required.

Governor Control from Switchboard.—There is also a governor control gear with a small reversible 3-phase motor worked by a simple reversing switch fixed in the control desk.

A reverse current relay is fitted on each generator switch and a time limit overload relay on each feeder switch. The spark gaps discharge to a common earthing system as shown in Plate No. XI. consisting of three $\frac{19}{12}$ bare copper cables connected in three places to the circulating pipes which terminate in the river.

Earthing of Generator Neutral Points.—An ingenious switch for the automatic earthing of the neutral points of the generator star windings is shown in Fig. 157. This apparatus consists of two sets of circular switches operated by a small direct current motor through worm gear. It so acts that if any running generator which has its neutral point connected to earth is shut down, either accidentally or purposely, then the switch automatically moves forward until it has connected the neutral point of another generator in circuit to earth. For a full description of this important piece of apparatus the reader is referred to Mr. J. H. Rider's paper on "The Electrical System of the London County Council Tramways," *The Institution of Electrical Engineer*, vol. 43, 1909. It is well

known that if the neutral point of each generator, when several are working in parallel, is connected to earth, heavy local interchanges of current of the third harmonic occur between the various generators through the medium of the earthing connections. For

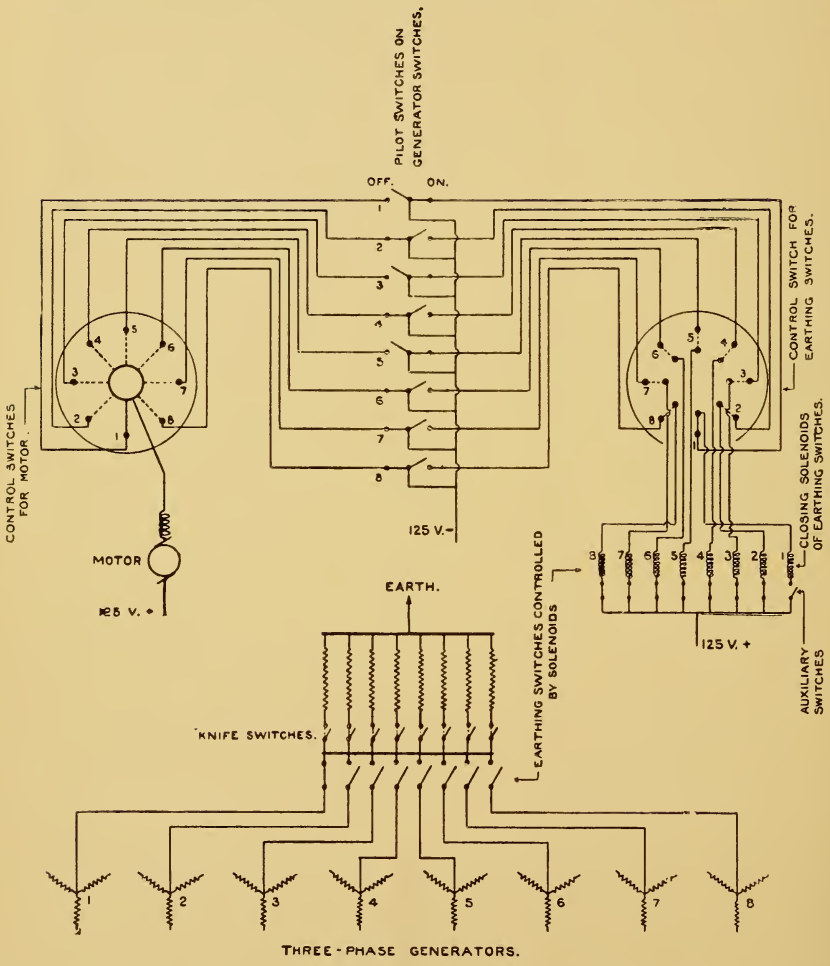
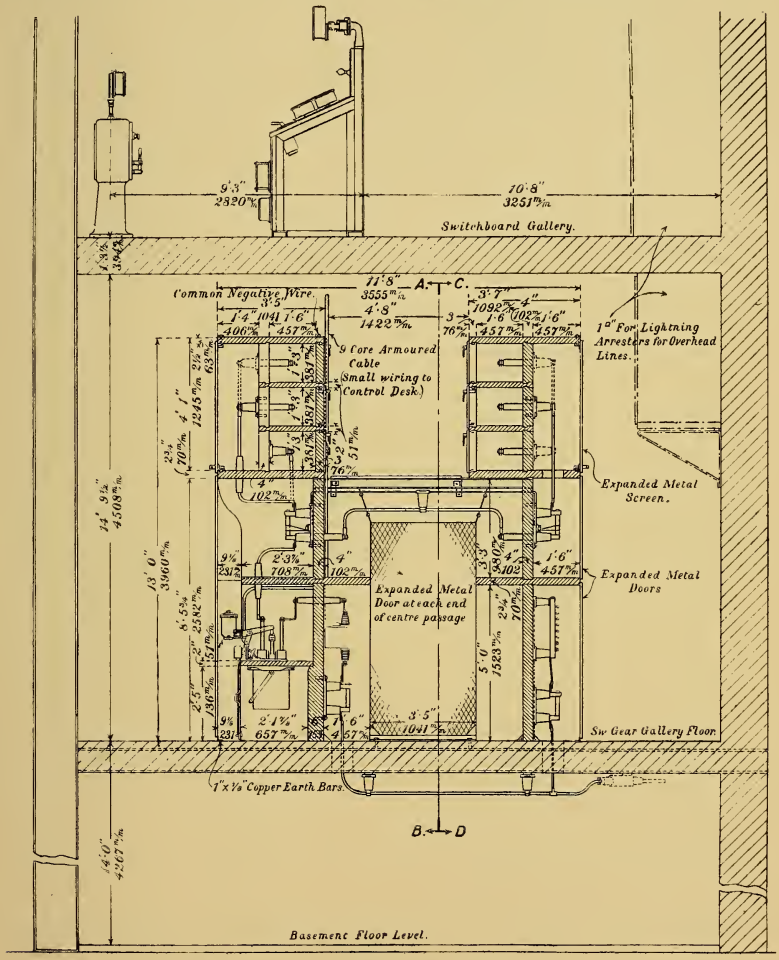


FIG. 157.

this and for other reasons it is important that only one generator should have its neutral point earthed.

Plates Nos. XI. and XIII. show the auxiliary low tension switchboards for the motor, lighting and other circuits in the power house.

Bahia Blanca H.T. Remote-controlled Switchboard.—Fig. 158 shows a section through the operating gallery and cubicle gallery in the Bahia Blanca power house and Figs. 159 and 160 front and


Switchboard Gallery.
Common Negative Wire.
9 Core Armoured Cable (Small wiring to Control Desk.)
1" For Lightning Arresters for Overhead Lines.
Expanded Metal Screen.
Expanded Metal Doors
Expanded Metal Door at each end of centre passage
Sw Gear Gallery Floor.
1"x⅛" Copper Earth Bars.
Basement Floor Level.

SECTION OF FEEDER PANEL

FIG. 158.

back views respectively of the cubicles. Plate No. X. is a diagram of connections, and Fig. 154 a photograph of the operating desk.

Duplicate H.T. Bus Bars.—In this case the main bus bars are

duplicated, and each generator is connected through its series instrument transformer oil-break switch (fitted with reverse current relay) to isolating links on each sectional bus bar. Each feeder is also connected to both sectional bus bars by isolating

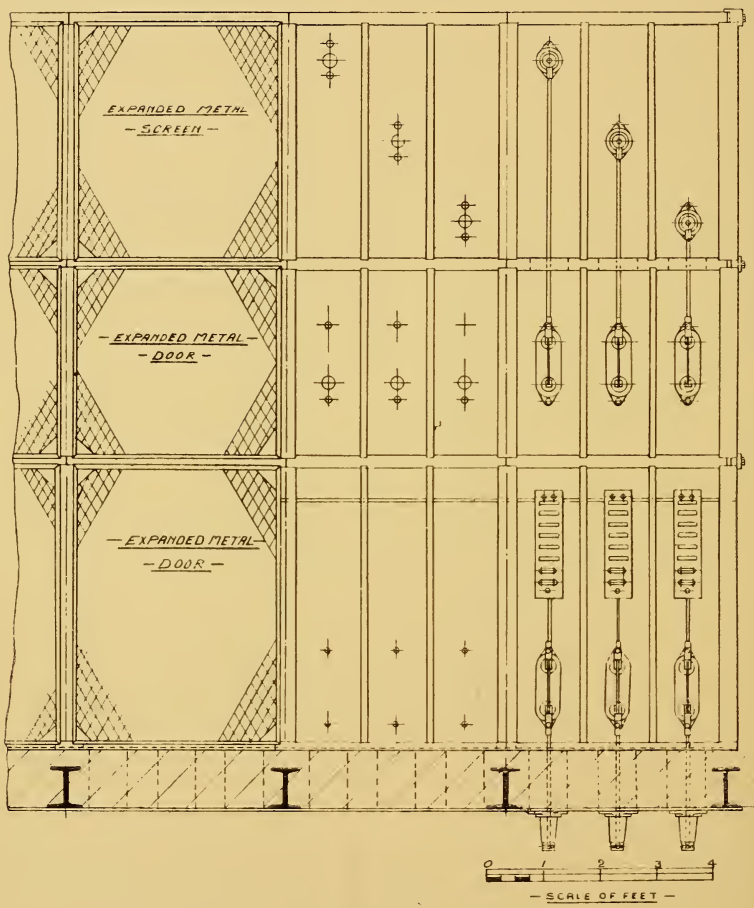


Fig. 159.

links, thence to the oil-break switch with time limit overload relay and series instrument transformer to the trifurcating box in which the three-core feeder terminates. On the operating desk each feeder or generator cubicle is represented by red and green

pilot lamps indicating which particular isolating links are in circuit so that the operator may see to which set of sectional

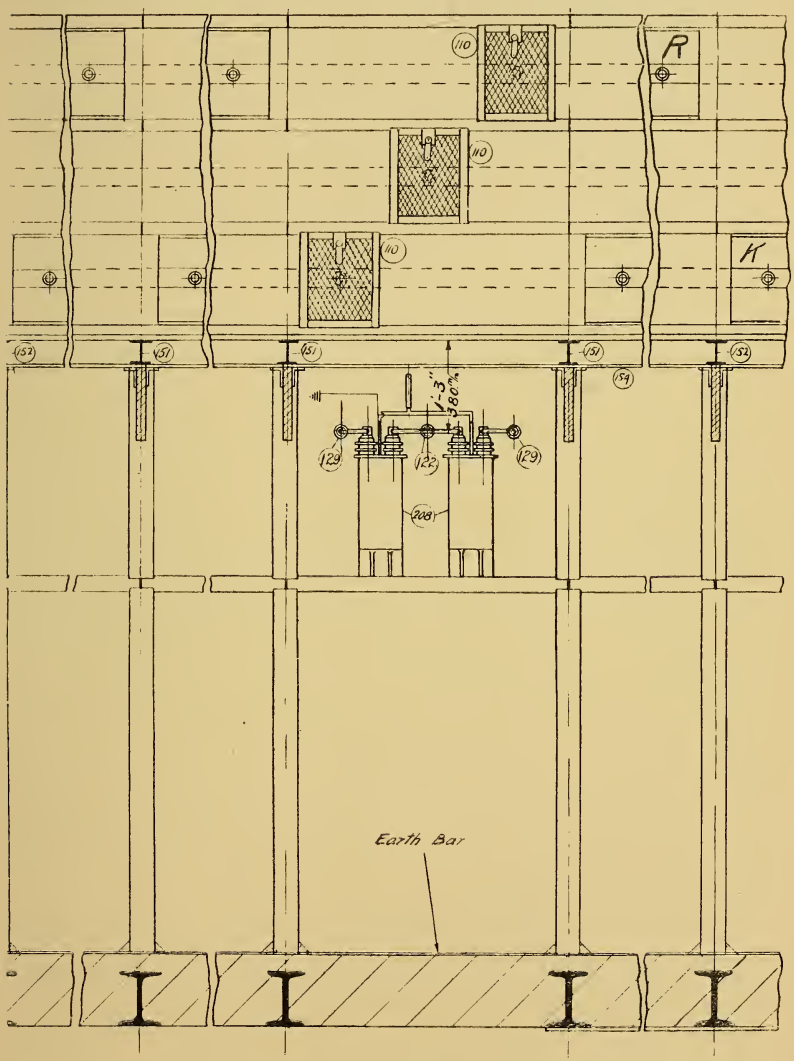


Fig. 160.

bus bars each machine or feeder is connected. This makes an extremely simple design of switchgear, with the additional

security against a shut down arising from the duplicate sets of bus bars.

The oil-break switches, instrument transformers, bus bars, etc., are contained with separate cells of moulded stone and protected in front by Bostwick gates fitted with Yale locks.

Some practical features of this switchgear will be of interest to the designer; the normal pressure on the board being 6600 volts between phases and 3850 volts to earth.

There is an air space of 6 inches around each phase bus bar, and the current density of the bars worked out on the overload capacity of the generators at 0·8 power factor does not exceed 1000 amperes current density per square inch.

Oil-immersed Switches.—The solenoid operated oil-break switches are arranged so that each phase is separately contained within its own sheet-iron cell which is lined with hard wood. The break between contacts when the switch is in the "off" position is not less than 4 inches. Phosphor bronze pins and bushes are fixed at all working joints of the switch mechanism so as to provide against rust, and consequent retardation of the quick action of the mechanism. The solenoids are operated from the 110 volt exciter circuit. No rubbing contact was allowed a higher current density than 100 amperes per square inch, and the permissible maximum current density of stationary carrying parts was 500 amperes per square inch. The series instrument transformers and potential transformers are contained within cast-iron boxes filled with diatrine.

The connections between switches and bars within the cubicles are of special fireproof cable, and instrument leads and indicating lamp leads are of best quality rubber-covered stranded wires run in screwed steel conduits.

The above-mentioned switchboard represents a simple layout, and yet contains all the essentials for complete safety of control and ease of working.

The designer should always take the latter item into consideration, and he is the more likely to do so if he has himself had running experience in a large power house. In emergencies the simple board has great advantages. As a typical specification for 3-phase high-tension switchgear the Author

reproduces some of the salient points he has adopted in his own practice.

Typical Operating Board.—Generator panel containing—

(*a*) Operating switch to control the oil-break switch solenoids.

(*b*) Synchronizing plug and receptacles.

(*c*) Indicating watt meter with transformers.

(*d*) Ammeter in one phase only, to read to 50 per cent. in excess of generator rated output.

(*e*) Three-phase integrating watt hour meter.

(*f*) Power-factor indicator.

(*g*) Reverse current relay, operating when 15 per cent. of the rated current is passing in a reverse direction.

Typical Feeder Panel.—Feeder panel containing—

(*a*) Operating switch to control the solenoid circuits to close or trip the oil-break switch.

(*b*) Three-phase integrating watt-hour meter.

(*c*) Overload time limit relay with a range of adjustment from, say 100 amperes to say, 250 amperes, and a time limit adjustment of from 5 to 30 seconds.

Typical Bus Bar Panel.—Disconnecting (or interconnecting) bus bar panel containing—

(*a*) Switch controlling the solenoid circuits to close or trip the interconnecting oil-break switch.

(*b*) Synchronizing plug and receptacles.

(*c*) Voltmeter with two potential transformers (one of each set of bus bars) and a throw-over switch.

Typical Synchronizing Panel.—Synchronizing panel or swing bracket containing—

(*a*) Bus bar voltmeter with illuminated disc and 18-inch scale calibrated say from 5500 to 8000 volts.

(*b*) Synchroscope with red and green signal lamps.

(*c*) Vibrating reed frequency indicator.

Typical Exciter Pillar.—Excitation control pillars each containing—

(*a*) Circular dial moving coil ammeter for the generator field circuit.

(*b*) Generator field rheostat hand wheel.

(*c*) Generator field-breaking double-pole switch with non-inductive resistance.

(*d*) Reversing control switch for governor motor.

Typical Transformer Panel.—Transformer panels (for supply of auxiliary power within the station) each containing—

(*a*) An operating handle to control the oil-break switch.

(*b*) Ammeter complete with instrument series transformer.

In addition to the above schedule of H.T. switchgear there are usually the L.T. excitation and L.T. alternating boards. These may be summarised as under—

Typical Exciter Control Panel.—Separate exciter panels each containing—

(*a*) Ammeter.

(*b*) Integrating watt hour meter.

(*c*) Receptacles for paralleling voltmeter.

(*d*) Double-pole quick-break knife switch.

(*e*) Hand wheel for exciter field rheostat (the rheostat being fixed immediately behind the panel). A large voltmeter with illuminated dial should be fixed above the board.

Typical Lighting Panel.—Power house lighting panels each containing—

(*a*) Ammeter.

(*b*) Main double-pole quick double-break knife switch to carry the whole current required.

(*c*) A double-pole quick-action double-break knife switch to carry the current in each separate circuit (one to each branch).

(*d*) Two single-pole porcelain-handle switch type fuses for each branch circuit.

Typical Low Tension A.C. Board.—The following auxiliary panels are generally required—

1. Power House transformer panels each containing—

(*a*) Hand operated oil-break switch with automatic quick "make" and "break."

(*b*) Indicating watt meter with instrument transformers.

(*c*) Integrating watt-hour meter with instrument transformers.

2. Motor control panels for the various motors or groups of motors throughout the power house, such as condensers, fans, travelling cranes, etc., each containing—

(*a*) Hand operated oil-immersed switch fitted with automatic A.C. trip coil;

(*b*) Ammeter; or,

(*a*) Triple-pole knife switch;

(*b*) Three porcelain handle switch type fuses;

(*c*) Ammeter;

according to the size of the motors or groups of motors controlled.

Requirements in a Well-designed Board.—The designer would do well in laying out his switchboard to arrange it so that the following special provisions can be effectively obtained—

(1) Separation of the mechanism either in cubicles or on different galleries, so that in the event of a burn out of one oil-break switch any explosion or flame resulting may not affect the neighbouring cells, or by access to the main bus bars, continue the short to them. The same remark applies to instrument transformers. It must be remembered that a very important railway power house was shut down and the whole traffic stopped through the burning out of an instrument series transformer and the communication of the arc to the apparatus above it.

(2) Safe accessibility to all the parts for cleaning and inspection. This entails a design which must necessarily have duplicate or sectional bus bars and such a system of isolating links that the section to be inspected may be positively disconnected. Insulators must be kept clean, and thus a periodical system of inspection and cleaning must be insisted upon.

(3) Facilities for removing the cases of oil-break switches so that the contacts and insulators may be periodically examined and the oil periodically changed. This last matter is one of very great importance.

(4) The careful selection of either moulded stone for the cubicles, which shall be so made up as to be practically non-absorbent of water; or of hard, well-burnt, first-quality glazed bricks.

(5) Liberal space around the cubicles and switch gear generally, as well as a thoroughly good light.

There are other types of operating boards, such as small dummy diagram boards, having the main connections picked out in relief on the face so that the operator sees exactly from this

model what switches are "on" and which are "off." An illuminated dial may be used, which by a system of lamps will also show the same thing pictorially. The Author thinks, however, these are quite unnecessary complications, involving a good deal of small low-tension leads and making the switch gear unnecessarily complex.

In the Author's opinion the best practice is to arrange the H.T. switchgear, in a large and important power house, in a separate switch house built as an annexe to the main building. Such an arrangement was designed for the large power house projected for the supply of the County of London, and has been adopted at the new Dunston power house of the Newcastle-on-Tyne Electric Supply Co., and elsewhere. So much depends on the safe working and control of the main switchgear, that this will be found a wise provision to make.

Isolated Pedestal H.T. Switchgear.—For very large machines the pedestal and self-contained type of gear has a good deal to commend it. The energy carried by each switch is so great that in the event of a fault occurring in the switch, isolation may prove to be very necessary. The following is a brief description of the 13,000-volt switchgear at the Dock Sud power house of Campanhia Allemanna Transatlantica, at Buenos Ayres:—The switchgear is situated in a very spacious annexe to the engine-room, as shown in the sectional view in Fig. 5. Each generator, as well as each feeder, has a separate and independent control panel containing the usual pilot switch for the remote controlled motor operated oil-break switch situated in an isolated cubicle below, as well as the necessary instruments, synchronizing gear, and excitation control instruments. There is also a master control desk from which the operator can control the independent panels and their machines and feeders. There is an abundance of room and to spare, and the Author's criticism is that while adopting properly the independent panel system for such large units and so high a pressure (13,000 volts), there is an apparent want of system about the grouping of the switchgear, which is very much scattered. This is to some extent made up by the master control panel. The cost of the switchboard annexe and switchgear distribution must have, however, entailed unnecessary expense

without the corresponding safety of the arrangement advocated in the previous paragraph.

Another type sometimes adopted may be called a solid or iron-

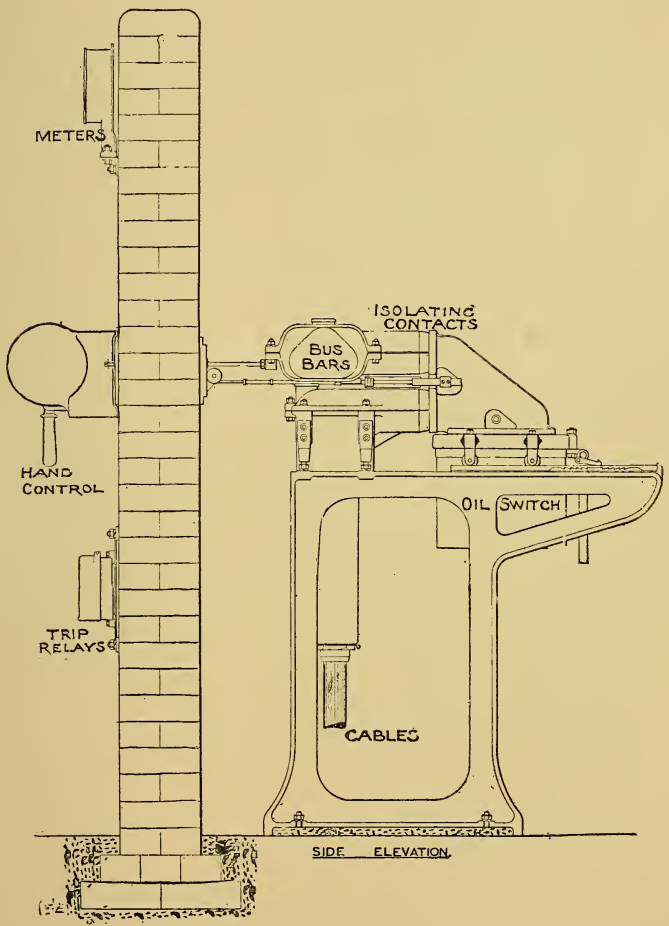


FIG. 161.

clad system, in which the bus bars are completely encased and thus made dust and moisture proof.

Fig. 161 shows an elevation of a remote control gear of this type as made for pressures up to 12,000 volts, together with a

front view of the operating side shown in Fig. 162. The chief claims of this type of switchgear are—

(*a*) Accidental contact with live metal is impossible.

(*b*) Dust, moisture, or vermin proof.

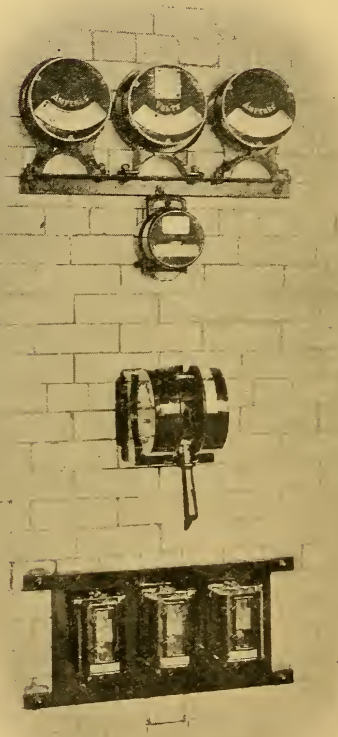


Fig. 162.

(*c*) Fire and short circuit risks minimized.

(*d*) Minimum amount of cleaning.

(*e*) Insulation able to withstand any excessive pressure likely to arise on the system.

(*f*) The parts requiring cleaning or inspection are readily and completely detached from the bars, so that the inspection may be carried out in absolute safety.

(*g*) Switch mechanisms are so situated as to be under observations.

(*h*) Mechanical strength.

Fig. 155 shows a H.P. panel suitable for arrangement on a system of independent panels. The locking-off doors on the 3-phase connections are shown by which all live parts are protected when the switch is removed for inspection.

In some Continental power houses the oil switch, etc., is carried on a traveller which can be drawn out from its cubicle so as to be positively disconnected and readily inspected and cleaned. For high pressure and extra high pressure switchgear, however, a fixed system is to be recommended giving greater rigidity and

less chance of broken insulators. Provided it is so designed as to embody the principles set out above, the fixed system has advantages over any "carrier" system. Consideration of space ought not to come in as the designer must always be liberal when laying out H.T. gear.

Switch and Transformer Oils.—Before leaving the high pressure switchgear, some mention of the oil to be used in switches and in transformer-cases may be made. This is a most important matter.

The oil chosen should be of a high dielectric strength with a flash point not less than 177° C., and free from water, sulphur compounds, acids or alkalis. A very minute amount of water present in the oil, such as may result from condensation inside empty steel drums, is sufficient to reduce the dielectric strength enormously and to become a serious danger, especially when used in oil-break switches. It is usual to specify that the oil shall have a dielectric strength sufficient to withstand, without breaking down, an alternating pressure of 14,000 volts measured between needle points $\frac{1}{8}$ of an inch apart; and that its viscosity shall have a value of 7 minutes with Redwood's viscosimeter and at a temperature of 35° C.

The oil should be tested periodically—in oil-break switches say once in every six months, and in main transformers say once every year. There is a portable apparatus sometimes used on extra high pressure systems which pumps out the oil from the transformer casing and subjects the oil to a considerable heat from steam coils so that any moisture present is driven off, the oil being then returned to the casing.

Direct Current Boards.—These main switchboards in power houses are more complex than alternating current boards. Direct current power houses usually have to supply two independent systems, one for general supply, usually on the 3-wire system, and the other for traction. There is the further complication arising on the general supply section in the requisite balancing and middle-wire-earthing apparatus and also the usual auxiliary battery control panels.

Some designers have adopted one main switchboard common to both systems. The Author thinks this is a practice to be

deprecated, as it involves much complication and crowding, especially at the backs of the panels as well as a mixing up of bars at differing potentials. There is nothing to be gained except perhaps a small amount of space. It is far better to keep the traction board distinct from the general board.

L.T.D.C. 3-wire Supply Board.—The following description of a typical general supply direct-current board may be given. Each panel usually contains and accommodates one generator and one feeder. There are two sets of bus bars, *i.e.* the main bus bars and an auxiliary set so that long distance feeders or a faulty section outside may be run on separate machines.

Fig. 163 shows the front views of the operating panels and the aluminium rod connections of the new 3-wire low tension switchboard designed by Mr. Bernard Jenkin, and erected at the Horseferry Road Station, Westminster. To get a maximum available amount of operating panels the boards are arranged to form three sides of a rectangle, the generator panels being kept mainly on the front and the feeders on the two sides of each group.

The whole of the connections and the heavy bus bars are of aluminium, and run direct from the backs of the panels to the end of a long tunnel, where they join the special end busses of the street cables. The board and the whole arrangement of connections is one of the neatest and best controlled the Author remembers to have seen. It is quite fireproof, the bare aluminium rods being supported by porcelain insulators in frames; and the poles are kept well apart. Practically the only danger is from the accidental earthing of one of the conductors, and this is well-nigh impossible owing to the well-designed arrangement of the conductors.

Each generator panel contains the following instruments:—

(*a*) Reverse current circuit breaker on one pole.

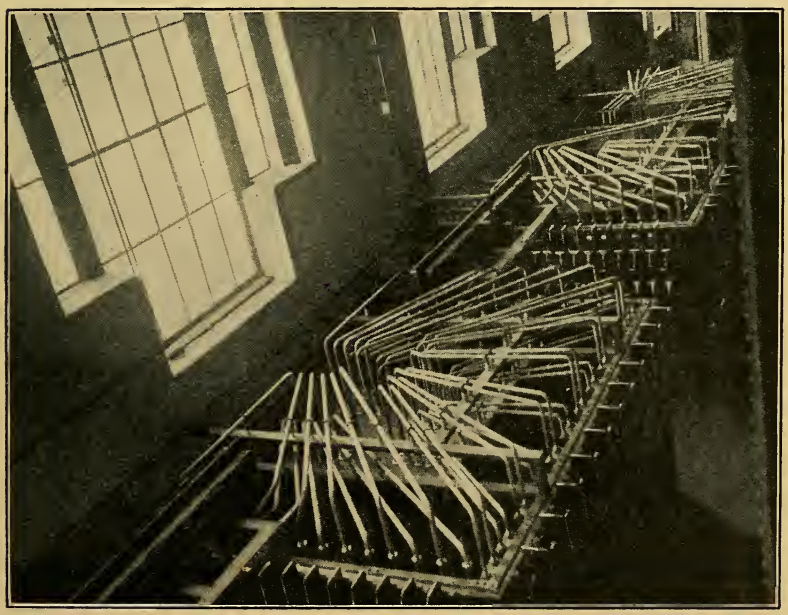
(*b*) Main quick break knife switch on the other pole.

(*c*) Machine ammeter and shunt.

(*d*) Paralleling receptacles for voltmeter.

(*e*) Vertical straps for plugging machine to either set of bus bars (or alternatively a throw-over switch by which the machine can be connected to either set of bars. This latter arrangement is

Elevation.



Plan.

Fig. 163.

preferable as it is positively protective against a mistake of plugging a machine on the wrong bars).

(*f*) The integrating watt-hour meters are usually fixed separately so as to prevent overcrowding on the main board. These may be conveniently fixed on the wall at the back of the board, within observation, but away from interference by unauthorized persons.

Each feeder panel usually contains the following instruments:—

(*a*) Main switch, on each pole, capable of carrying the maximum probable overload on the feeder.

(*b*) Ammeter and shunt, one on each pole (unless the system be a simple 2-wire).

(*c*) Magnetic blow-out fuses, or what is preferable, overload time limit circuit breakers. These latter must be set well above normal or probable overload currents, or momentary short circuits outside may dislocate the supply.

(*d*) Vertical bus bars and plugs for connection to either of the duplicate horizontal bus bars.

A middle wire and balancing panel, containing instruments, (*a*) for earthing the middle wire, and (*b*) for balancing purposes.

The earthing arrangements contain—

(*a*) Ammeter with middle zero, so as to read the out-of-balance current on either side of the 3-wire system.

(*b*) Step switch for controlling the resistance through which the middle wire is connected to earth. The resistance is situated away from the board.

(*c*) Fusible cut out to disconnect the middle wire in the event of a heavy ground outside on either of the outside conductors, and cut in the resistance.

The balancing arrangements contain—

(*a*) A double pole switch to control the balancing transformer motor.

(*b*) Field control switch for same.

(*c*) Double pole switches for each generator, one positive and one negative.

(*d*) Ammeter on each balancer.

In addition to the above the equipment requires—

(*a*) Complete set of pilot voltmeters, including large illuminated voltmeters with 18-inch dial on each side of the middle wire.

(*b*) Multiple pilot switch to control the pilot leads on each feeder. The pilot leads are best brought to a supplementary assembly board away from the main board, with leads taken thence to the multiple switch on the main board.

If a battery is used then a supplementary panel will be required for its control. The arrangement will depend on the type of booster adopted, but generally the panel will contain—

(*a*) Main switch on each pole.

(*b*) Circuit breaker on each pole.

(*c*) Ammeter to read both charge and discharge.

(*d*) Voltmeters.

(*e*) Booster switches according to the type used.

The battery input and output energy meters are usually fixed separately and away from the main board.

The principal points to be observed in laying out direct current switchgear are—

(*a*) To group the panels so that the operator can control the generators especially, and the feeders connected to the board, without having to do a "sprint" each time some regulation has to be made.

(*b*) Plenty of space both in front and behind the board. The latter should not be less than 4 feet 6 inches from the outermost conductor on the back of the board to the wall, or to the meter cases if fixed on the wall. Head room must be also considered so as not to have conductors from the board to the wall giving less than a 6 feet 6 inches clear headway.

(*c*) So to space the bus bars and straps as not only to give accessibility for cleaning and for adequate cooling area, but also that connections may be tightened up without risk of short circuit or shock. Bus bars are sometimes taped, but in any case they must be kept several inches from the backs of the panels so that they have a clear air space from the connecting straps on the panels and from the steel framework.

(*d*) Small instrument leads on the back of the panels should be reduced to a minimum in number, and neatly and symmetrically run on porcelain insulators. All connections should be at the

backs of the board. Fireproof leads should be used. Connections through the panels should be bushed.

(*e*) Feeder cables should terminate away from the board and be continued by bare copper rods or straps to the bars. The idea being to keep all possible inflammable material away from the board.

(*f*) On the operating side, switches should be so arranged as not to stand out when in an "off" position and block the passage way. Instruments should be arranged at a level where they can be read by the operator without either breaking his back or ricking his neck! Circuit breakers or fusible cutouts should be fixed at the tops of the panels, so as not to "blow" in an operator's face, or even, by the vaporized metal, to cause an arc in the connections above them, as they would do if situated lower on the panel. Resistances for field rheostats, etc., should be fixed well away from the panels, and in most cases separate excitation pillars are preferable, so as not to congest the main board. On the whole, either white or grey marble slabs, with instrument cases finished dull black, are best, as they have a good appearance, and also minimize the amount of "powder and polishing paste." Marble, if free from metallic veins, is better than slate, being less absorbent; though with direct current boards dust figures may form around the negative connections if the board be not kept scrupulously clean, and if any oil vapour is present the marble may be stained.

The heavy bus bars should be carried on brackets from the steel framework, with insulators, so as not to throw strains on the marble or slate.

Slate must, of course, be enamelled both back and front, and has a sombre appearance especially if the instrument cases are finished dull black; on the other hand, lacquered brass or even aluminium cases require a good deal of cleaning, which costs money.

For the working current densities of metals on direct-current boards, see p. 369.

An extract from the British Home Office Regulations (1909) is given in Appendix I. at the end of this book, and this should be referred to by the designer, as the Regulations embody the considered necessities for good and safe practice and are the result of

a lengthy inquiry at which the leading experts, contractors, and manufacturers were represented.

L.T.A.C. 4-wire Supply Board.—For 3-phase 4-wire distribution the switch board illustrated in Fig. 164 may be taken as a type.

This consists of—

1. Six transformer control panels for supplying the general network.

2. Twelve outgoing feeder panels.

3. Street arc lighting panels to control the constant current transformers.

4. Power house auxiliary motors and lighting.

The panels are mounted in a mild steel framework bent to shape, rivetted up and suitably stayed, finished dull black, including the bolts and the instrument cases. The panels are of white marble 2 inches thick, straight bevelled at all edges, the bolts holding the slabs to the framework being bushed and capped.

Each transformer panel contains—

(*a*) A handle to operate the levers of the oil-immersed switch controlling the transformer secondaries.

(*b*) Three ammeters, one on each phase, with current transformers.

(*c*) One voltmeter on one phase, with potential transformer.

(*d*) Integrating watt-hour meter with current and potential transformers.

Each feeder panel contains—

(*a*) One oil-break switch operating handle, as above.

(*b*) Three ammeters, one on each phase, with series of transformers.

(*c*) One indicating watt meter, with potential and current transformers.

Each street arc lighting panel contains—

(*a*) Automatic oil-break switch, mounted on back of the panel, with lever handle in front, complete with trip coil and series transformers.

(*b*) Three long-scale ammeters, one on each phase, with instrument transformers.

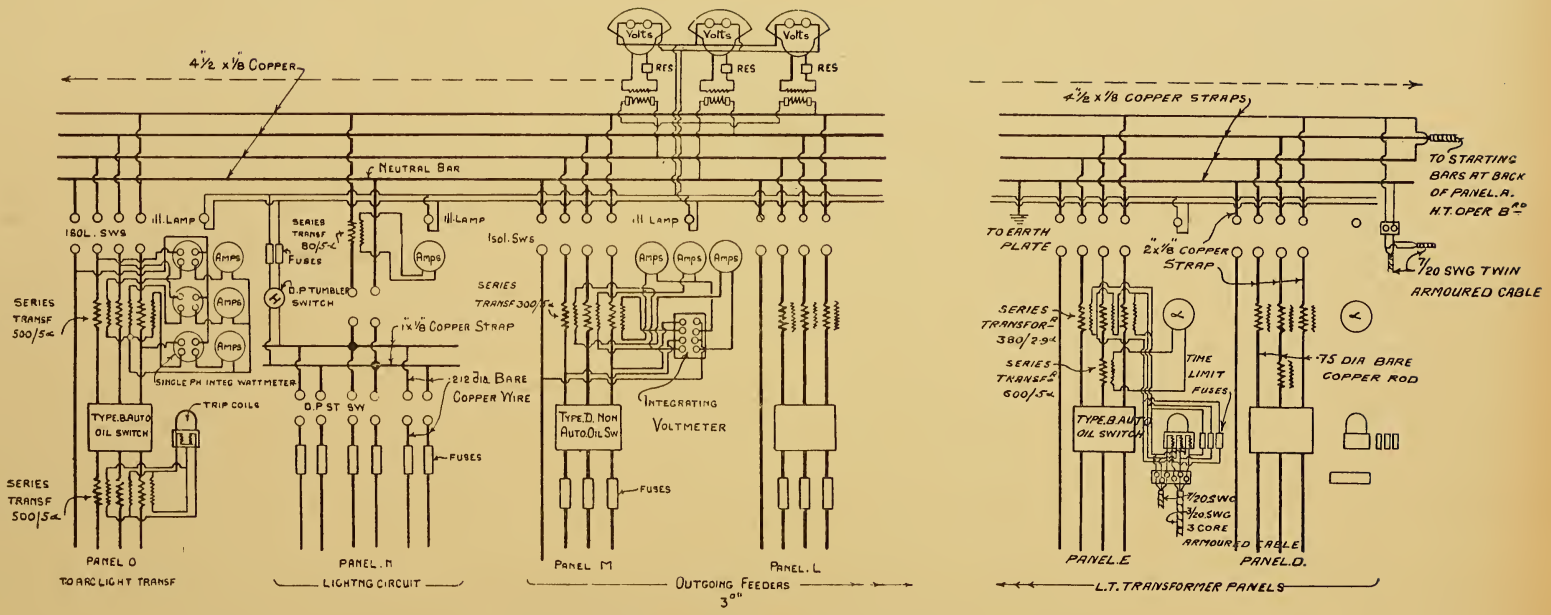


FIG. 164.—Diagram of connections of L.T.A.C. board.

(*c*) Three single-phase watt-hour meters (one for each phase), complete with instrument transformers.

Fig. 165.—L.T.D.C. traction board.

L.T.D.C. Traction Board.—Fig. 165 shows a typical traction board in use on the London County Council tramways. This has some special details in it not common to trolley systems, as the

conduit conductors have to be reversed in polarity from time to time. The track feeder panels have double pole change-over switches, so that the feeder controlled may be reversed in polarity without in any way interfering with the bus bar polarity. The change-over switch has auxiliary contacts on each pole both at the top and bottom positions. These auxiliary contacts are insulated from the main contacts. When the switch blades are pulled out of the main contacts into the auxiliary contacts, the track feeders are connected to the main bus bars through a fixed metallic resistance of 5 ohms and a special testing panel. By these means it is possible to see whether a fault in the feeders or conductor section is a bad one or not. The track circuit breakers are of the plain overload type without time limit. The generator circuit breakers are of the reverse current type; and in this case, as the board is supplied by motor generators, the circuit breakers are cut out by the use of a separate starting panel when the motor generators is being run up.

Traction Board with Rotaries.—Plate No. XV. shows a typical direct traction board for the control of four rotary converters and five track feeders.

Each rotary panel contains the following instruments—

(*a*) Change-over switch and pole indicator.

(*b*) Double pole quick break knife switch, to take maximum over load current.

(*c*) Ammeter with shunt.

(*d*) Integrating watt-hour meter.

(*e*) Equalizing knife blade switch.

(*f*) Receptacles for Kelvin paralleling voltmeter.

(*g*) Single pole circuit breaker, with reverse current trip coils, and copper rod choking coil.

(*h*) Adjustable reverse current relay with shunt.

Each track circuit feeder contains—

(*a*) Single pole plain over load circuit breaker and copper rod choking coil.

(*b*) Single pole quick double break knife switch, to take maximum feeder current.

(*c*) Ammeter and shunt.

(*d*) Lightning arrester complete with isolating switch.

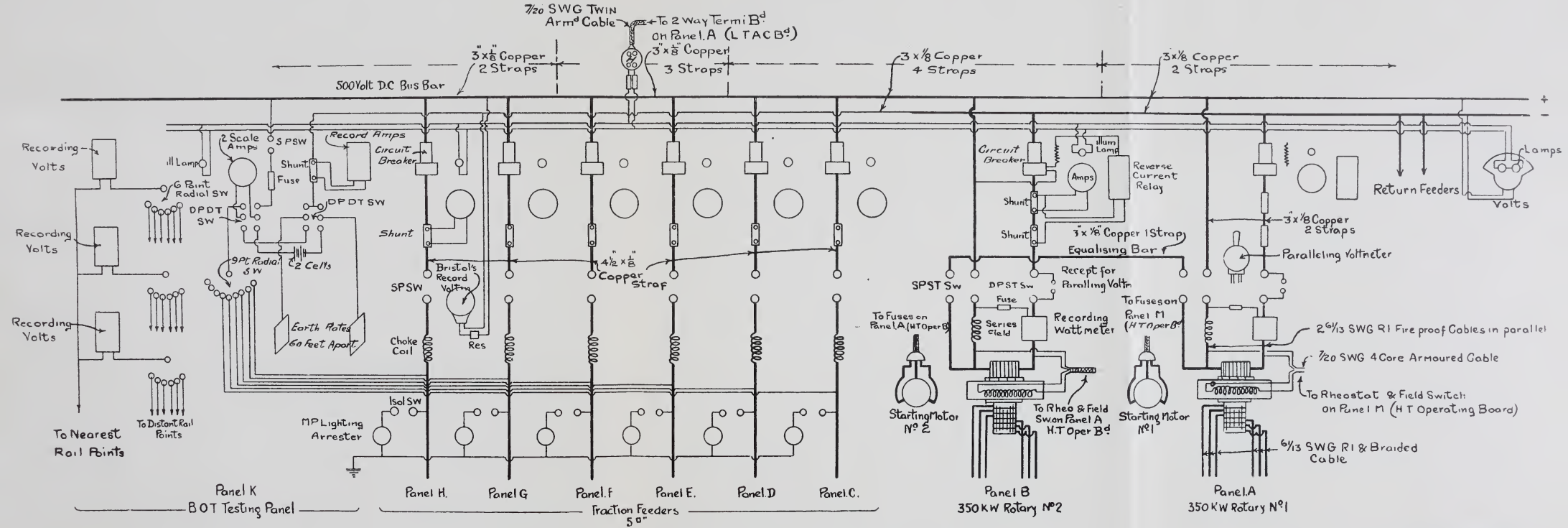


PLATE XV.—TRACTION BOARD WITH ROTARIES.

[*To face page* 368.

The leakage testing panel is fitted with—

(*a*) Double scale circular dial ammeter.

(*b*) Three recording voltmeters, with scale from 0–10 volts.

(*c*) Recording voltmeter for line voltage.

(*d*) Four five-point voltmeter switches for pilot wires.

(*e*) Two small knife switches for leakage ammeters.

Practical Notes on Switchboard Materials.—The following practical points may be considered when selecting switchgear.

Bus bars should be designed to work at not more than 1000 amperes per square inch current density. These may either be of copper or of aluminium. For large bus bars it is usual to build them up of metal strips with separators to enable a maximum radiating surface to be obtained.

The rubbing contacts of circuit breakers, etc., should not exceed 100 amperes per square inch at rated load, and switches 60 amperes per square inch.

Fixed switch parts, straps, links, etc., if of copper should not work at a higher current density than 800 amperes per square inch ; and 500 amperes per square inch if of aluminium. Similarly, the current density of brass should not exceed 250 amperes, gunmetal 200 amperes, and phosphor bronze 300 amperes per square inch.

Resistance grids should not have a higher temperature rise than 66° C. (151° Fahr.) at their rated current after one minute.

H.T. current transformers should be subjected to a pressure test of at least $2\frac{1}{2}$ times the working pressure for 5 minutes between primary and secondary as well as a heat run (before the compound is run in) for say 3 hours at rated load, 2 hours at 25 per cent. overload, and 15 minutes at 50 per cent. overload. At the end of this run the rise of temperature between any accessible part of the coils and the surrounding air not to exceed 40° C. (104° Fahr.).

Similarly, with potential transformers the H.T. windings should be tested for 5 minutes with a pressure of not less than $2\frac{1}{2}$ times the working pressure (the secondary being earthed during the test) ; the low tension windings at a pressure of 2000 volts for a like time.

They should also be subjected to a heat run for six hours

with a temperature limit as in the case of the current transformer above.

Instruments should be supplied with a margin of error not to exceed the following—

Voltmeters, ammeters, watt meters, and integrating watt-hour meters.

25 per cent. overload	2	per cent.
Rated load	1	„
$\frac{1}{4}$ to $\frac{3}{4}$ load	1·5	„
Below $\frac{1}{4}$ load	2·5	„

Overload time limit relays.

Time error, 3 per cent.; current error, 10 per cent.

Reverse current relays, 15 per cent. of full load at any pressure between normal voltage and one half normal voltage.

Space required for Switchboards.—If a high pressure board is necessary, then galleries have to be provided as shown in a previous Fig. (No. 158). If the outgoing feeders consist of cables, then the best sequence of galleries will be (1) basement, cable race, (2) cubicle and switch gallery at engine-room level, (3) operating gallery. The cables from the generators are then taken through ducts directly into the cable race to the trifurcating box fixed in an accessible position. The rubber tails are thence taken on suitable insulator supports to the terminals of the isolating links controlling the oil-break switch on the (engine-room level) floor above, and thence through the other apparatus to the bus bars.

Similarly, the feeders enter into and run through the cable race to trifurcating boxes, and thence to their control gear as in the case of the generators.

This enables a minimum length of expensive cable and also a minimum length of tails to be employed.

If the outgoing feeders are run overhead then the above arrangement may be reversed. The operating gallery may either be at engine-room level or in a more commanding position above, and the switch gallery can be made the floor above the operating gallery, as shown in Fig. 176.

When cables are run vertically up the walls of the building

glazed brick chases can be built into the face of the wall at the time of construction and in which the cables can be neatly run and cleated.

Due regard must be given to the good lighting of these galleries both by day and by night, and also to good ventilation.

The clear distance between floors should not be less than 8 feet. The gallery at the front and back of the cubicles should not be less than 3 feet 6 inches in width in each case.

Distributed Weights on Galleries.—The usual concentrated weight of the stone cubicles, oil-break switches, etc., is 3 cwt. per square foot (excluding the weight of the concrete floor). The filling between the steel joists forming the floor is of concrete, and cutting away should be avoided by inserting boxes in the concrete at the necessary points so as to have holes through the floor for the cables. The cubicles must of course be arranged in respect of the rolled steel joists so as to enable the cable access holes to be symmetrically spaced out, and not to foul a joist.

Direct current boards require of course only one gallery, or can be placed on a dais in the engine-room. The clear space required in front of a board (measured from any projecting connections) should not be less than 3 feet, and behind 4 feet 6 inches; a clear head room behind the board between the floor and any connections running overhead should not be less than 7 feet. Very careful attention to these dimensions was given by representative inquiries during the framing of the Factory Regulations for Great Britain, and the above-mentioned figures were the minimum fixed, see Appendix III. which contains an extract from these Regulations, already referred to. Good light must be allowed both in front and behind the board. The floor should be laid as to prevent any attendant from making "earth" when working on the connections at the back of the panels. Resistance can be fixed below the floor level or on the wall behind the board, the clearways given above must of course be independent of such fixtures.

Important Notes for Designers.—For very large power houses, as has been urged before, a separate switch annexe to the main building should be constructed, allowing ample space for the gear and the cables.

In laying out a power house the designer should also lay out

the general switchgear, as in many cases, while adequate attention is given to the plant and piping, flues, etc., too little attention is paid to the switch room, and a rough space only having been allowed it may be afterwards found that the gear is cramped and the space for inspection and clearing, or for repairs, inadequate.

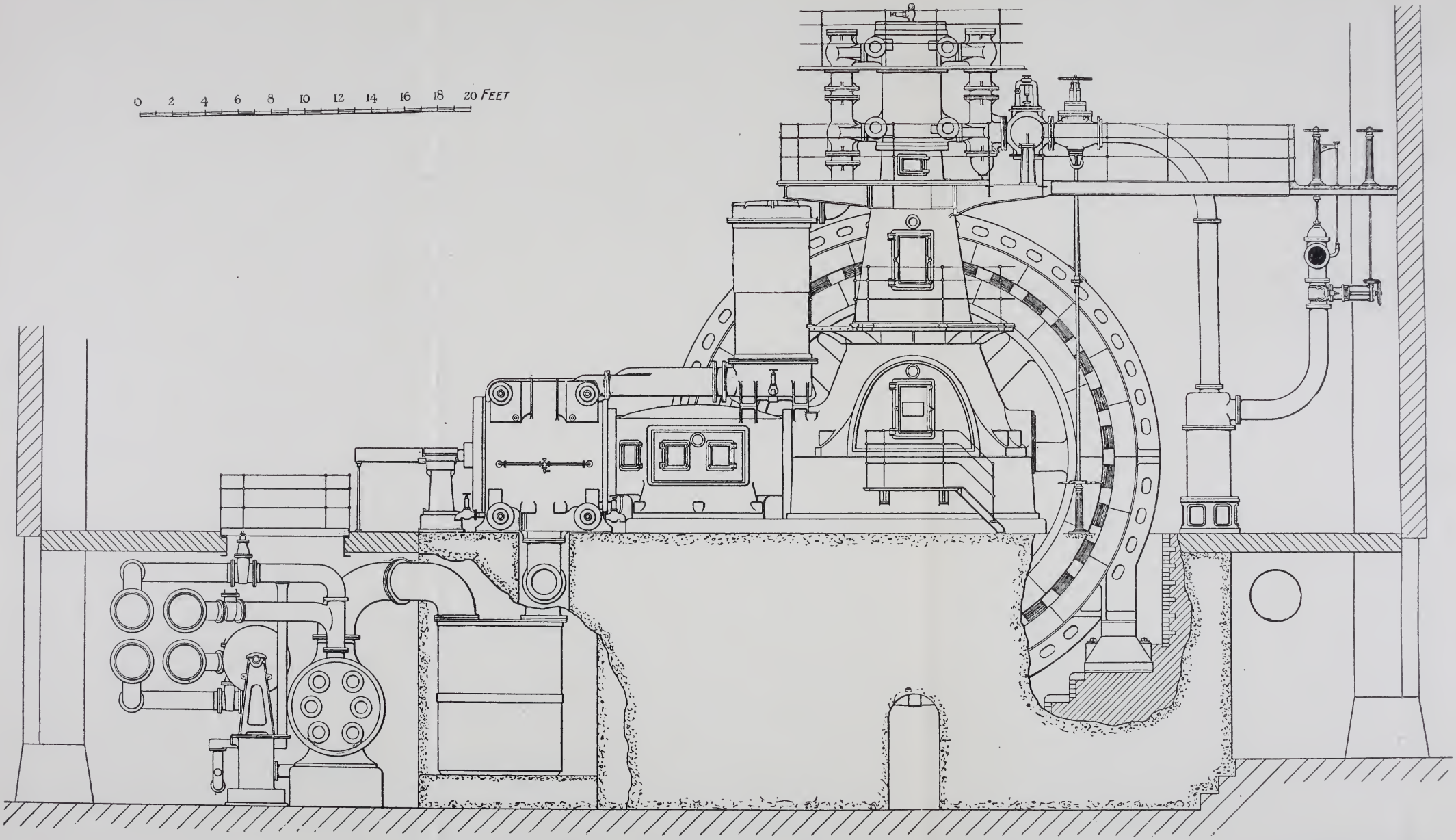


PLATE XVI.—SLOW SPEED (88 R.P.M.) THREE-PHASE 3500 K.W. GENERATOR.

[*To face page* 373.

CHAPTER XI

SOME PRACTICAL NOTES ON GENERATORS, MOTORS, BOOSTERS, TRANSFORMERS, ETC.

A FEW practical notes and references are all that need be made under this section. This work does not profess to deal with the design of machines, but only to give practical details of the kind requisite to the designer of power houses, such as weights, spaces occupied, and so forth.

Generators.—The types of generator available are:

A. Slow speed—(*a*) 3-phase, low, medium, or high voltage;
(*b*) 1-phase, low, medium, or high voltage;
(*c*) Direct current.

B. High speed—(*a*) 3-phase, low, medium, or high voltage;
(*b*) Direct current.

Typical Slow-speed Alternator.—A typical slow-speed (88 R.P.M.) 3-phase generator is shown in Plate No. XVI. This machine has a rated output of 3500 K.W. at a power factor of 0·94. This 3-phase generator is of the revolving field type with 34 poles and a working pressure of 6600 volts between phases at 25 cycles per second. The field magnets are built up of laminated steel stampings held in dovetailed slots in the rim of the wheel and kept in place laterally by heavy steel plates and rivets which go right through them and through the wheel. The windings are of bare copper tape laid on edge one layer deep. The pole tips are specially tapered off, and fitted with damping coils made up from a copper ring fixed right round the outer edge on each side, and fitted with copper rivets going through the pole tips from one ring to the other.

The exciting current of these 3500 K.W. sets (rated at a P.F. of 0·94), is, at full load, 400 amperes at 125 volts, or 1·43 per

cent. The stator core has five open slots per pole per phase, the coils being former-wound, there being fifteen conductors per hole per phase, or three conductors per slot. The coils are held in position by hard wood wedges running in dovetails.

Typical Turbo Alternator.—A typical turbo generator, shown in Plate No. VIII., may also be briefly described. The 5000-K.W. Willans-Dick-Kerr generator is coupled to a 750-R.P.M. steam turbine and has a revolving field with salient poles. This has been taken merely as a type, and it is, of course, understood that there are very many other manufacturers who make similar machines of equal excellence, and reference should be made to the next paragraph as to the type of rotor.

The output of 5000 K.W. is calculated on a power factor of 0·85, and the efficiency is 96·2 per cent. at full load at that power factor. The frequency is 25 ~ per second.

The frame of the stator is of cast iron; the coils are built up on the solid system and drawn into the slots and are insulated with mica. The coils were tested to 25,000 volts at the works. The stator has six slots and eighteen conductors per pole per phase. Special ventilating ducts are provided in the frame and laminations, stiffening fingers on the outside of laminations being fixed to obviate danger of vibration. The complete weight of the stator is 42 tons.

The rotor has four poles, and the body is built up of a central solid steel casting with salient poles, and cast under pressure. The central body is machined and bored out to a diameter larger than the shaft. Two cross-shaped pieces are built up at each end of the central body, and they carry the rotor on the shaft, so arranged in reference to the shaft as to leave an ample space all round for ventilation. The rotor is pressed on to the shaft at about 100 tons pressure. On the central body radially drilled passages are provided which correspond to the air ducts in the laminated pole tips. These pole pieces are dovetailed into the central casting. Special end-pieces are also dovetailed into the casting to retain the laminated tips in position and at the same time to act as checks on the centrifugal forces acting on the spools. So as to guard against the centrifugal forces which tend to spread the coils, wedge-pieces are inserted between adjacent coils pressing

against both them and the pole tips. The complete weight of the rotor is 20 tons, and the peripheral speed 10,000 feet per minute.

The field windings are built up of solid copper strips wound on edge, insulated between turns by paper and mica, and supported in a special copper spool with heavy insulated flanges. The spools after being formed and insulated are subjected to hydraulic pressure in the axial direction up to 50 per cent. in excess of that to which they would be subject from centrifugal stresses under normal working. As the copper winding bears flat on the insulation there is no danger of cutting. The spools are ultimately finished on the outside surfaces by a special varnish, both oil and water proof, giving both a very hard and a glazed surface.

The collector rings are made from a special grade of cast iron, fixed over a solid steel sleeve. They are of special construction so as to make it impossible to be subject to deformation under working conditions. The collector rings are shrunk hot over special micanite bushes built up directly on the steel shell of the ring.

The exciter is connected to the alternator shaft by a flexible coupling, and is carried in two spherically seated bearings. The excitation is 300 amperes at 125 volts at full load, or 37·5 K.W., *i.e.* 0·75 per cent. of the generator rated load. The commercial efficiences, including friction, windage, and rheostatic losses, are as set out in Table CXIV.

TABLE CXIV.

Output in K.W.	7500.	6250.	5000.	2500.	1250.
Efficiency P.F. = 1·00 .	97·25	97	96·4	93·6	88·2
,, P.F. = 0·85 .	—	96·7	96·2	93·5	88·1

The generator can carry an overload for two hours of 6250 K.W. at a power factor of 0·85 at normal pressure and speed.

The temperature rise when continuously working for not less than 12 hours (with natural ventilation) is such that no part of either the stator, rotor, or exciter exceeds 70° Fahr. above the surrounding atmosphere.

Type of Rotor in Turbo Alternator.—Turbo alternators are, on the whole, better provided with cylindrical type rotors rather than with salient poles. The former type having the windings distributed in slots affords more cooling surface, and there is less magnetic leakage. Moreover, the winding space is more efficiently utilized, the salient pole type requiring to be filled in with supports to prevent distortion or slipping under the large centrifugal stresses set up at the high peripheral speeds when turbine driven. Such a rotor can be also constructed with great mechanical strength, and with but little liability to get out of balance, an extremely important matter in high speed generators.

Stator Slot Windings.—From the brief descriptions of typical slow and high-speed alternators given above, it will be noticed that there are only three conductors per slot, thereby reducing the voltage between neighbouring conductors to reasonable limits of 440 volts in the slow speed, and 366 volts in the high speed. This is of importance in the design, and also in the endurance of the machine, as it enables a proper factor of safety to be adopted in the slot insulation, between neighbouring conductors. Hence the remark previously made that it is advisable in high pressure transmission schemes to restrict the generator pressure to the reasonable standard of 6600 volts—an empirical figure, it is true, but one also reasonably practicable—and to step up this pressure to the line pressure by means of static transformers. The chances of brush discharge from the windings are thus reduced in practice to a negligible quantity.

Stator Slot Insulation.—The question of insulation is very important, especially for machines required to work in tropical or semi-tropical climates or in wet districts. The following specification for slot winding has been found by the Author to withstand these climates with success.

Each stator coil to be made up from bare copper strap one turn above the other and completely wound on a former. Each turn to be taped all over with unimpregnated No. 2 cotton tape. A sheet of mica about 10 to 15 mils. in thickness (consisting of mica splittings pasted on to Japanese paper with flexible mica varnish) to be interleaved between successive turns within the slot-length. The whole coil then to be taped with No. 2 tape, non-

overlapping, and impregnated *in vacuo* with a clear baking varnish and subsequently to be baked dry.

The ends of the coil outside of the slot then to be taped with three layers of Empire cloth (bias taped), each layer to be varnished with one coat of clear baking varnish and to be baked dry before the next layer is applied. The first of these three layers to extend right up to the point where the coil projects from the iron, the two other layers to finish each 1 inch further out than the underlying one, so as to taper off.

The coil within the slot and for a length of 3 inches beyond each side to be served with a covering of pure Indian mica, $\frac{1}{10}$ inch in thickness, built up with shellac and pressed on hot. The whole of this mica tube then to be tightly enclosed in a close-fitting sheath of leatheroid and carefully coated with a thoroughly waterproof oil-resisting varnish. A trough of leatheroid treated with paraffin wax to be fitted in the slot as a further mechanical protection to the finished coil. The mica covering to be tapered in thickness at the ends so as to correspond with the taper on the Empire cloth covering. The coil to be firmly held in position in the slot by a wedge of seasoned hornbeam.

The end portions of the coil then to receive three further tapings of Empire cloth, each overlapping the mica cell and reaching up to the point where the coil leaves the iron. Each layer to be well varnished.

A final taping of No. 2 cotton tape impregnated with a clear baking varnish to be then applied, after which it is to receive two coats of an approved air-drying varnish. The portions of the coil where the taping overlaps the mica cell to be tightly bound with a hard twine.

Field Coils.—The field coils to be former wound with rectangular section wire, double cotton covered and painted with electro enamel as the coil is wound on. One turn of $\frac{1}{4}$-inch rope, impregnated *in vacuo* with insulating varnish, to be fixed in the corners in the inside. The inside of the coil to be protected with two layers of $\frac{1}{32}$-inch leatheroid, both layers to be bent over in the straight parts of the coil so as to protect the top and bottom portions over the full width. A similar protection of four flanges of $\frac{1}{32}$-inch leatheroid to be placed at the top and bottom inside

the brass flanges of the spool. The formed coil to be impregnated *in vacuo* with a clear baking varnish.

Insulating Material.—Insulating materials vary so much in quality that makers should be required to submit samples to the engineer for testing. As much care is needed in this as in testing the steel for the shaft. Permeability tests of the iron can well be left to the manufacturers, as their compliance with the salient tests of temperature rise, regulation and efficiency will govern the quality of the iron used. But insulating materials may pass the high-pressure test and heat runs of a set quite well, and yet because of their hygroscopic qualities may break down some time after the machine has been taken over. For this reason the Author advises that the engineer should insist on making independent tests to a rigid specification.

These materials may be broadly classed into—

(A) Woven textures;

(B) Short fibrous material compressed in an unvarnished or otherwise untreated condition.

These should be made to pass the following laboratory tests; sensible and practical tests which have been adopted by Mr. W. P. Digby, who assists the Author in laboratory and testing work.

(1) *For A Class Materials.*—Insulation resistance to be not less than 100 megohms per square inch of surface, after 100 minutes exposure in a saturated atmosphere at 75° C.; the increase in thickness of the sample after the above test and when measured by a micrometer not to exceed 1 per cent.; the increase in weight (also after the first test) when measured in a balance not to exceed 2½ per cent. of the original weight.

(2) *For B Class Materials.*—Insulation resistance to be not less than 20 megohms per square inch of surface after 100 minutes' exposure in a saturated atmosphere at 75° C.; increase of thickness at end of test not to exceed 5 per cent., and increase of weight not to exceed 5 per cent.

Insulating varnishes must also be tested, as a good deal depends on these; slight brush discharges in alternating current generators may be a cause of serious trouble through the formation of nitric acid. The varnishes should be free from moisture, acids and alkalis, and such that a film when dried shall be plastic and

not brittle, of uniform thickness and resistant to or inert with both oils and acids. Cases are known where leaky glands on reciprocating sets have allowed oily vapour to be drawn in by the fan-like action of the generator. The oil has then condensed on the windings and broken down the insulation.

A dry film 0·002 inch in thickness laid on a plate of very thin metal should not give any noticeable increase or decrease of weight after being kept for 2 hours at a temperature of 95° C. with free access of air. It must also be so sufficiently plastic as not to show any signs of cracking when the metal plate is bent inwards and outwards through a right angle around a bar $\frac{1}{4}$-inch in diameter.

Former wound coils should be used where possible, that is a coil the conductors of which are bent to shape in a jig, insulated from one another and encased in the necessary slot insulation (which is usually moulded and pressed on) so as to be placed directly in the open slots without bending or straining the conductors, as explained fully on a former page.

Insulation Tests.—Each stator coil should be tested in slots (so as to represent the stator iron) with a pressure at least twice the normal rated pressure, alternating current, for a period of one minute. For example, with a 6600 volt machine the testing pressure for one minute should be 15,000 volts.

Rotor windings, or field coils, should be tested with 1000 volts alternating for a period of 5 minutes in each case applied between the windings and the frame.

Staying of End Windings of Alternators.—The staying of the end windings of 3-phase machines should receive careful attention, for in the case of a short in the system outside, heavy magnetic pulls result on these windings and consequent severe mechanical stresses. These may cause not only deformation in the end windings themselves, but also exert heavy leverage on the slot windings with resultant damage to the insulation at the entrance to the slots. Spacing blocks between coils are usually made from gum-impregnated ash bound to the coils with hard twine.

Wave-form and Parallel Running.—There is a third matter also requiring practical attention, viz. the easy parallel running of the various alternators. Care has to be exercised therefore when

selecting the design of a machine to see that the wave-form is as nearly as possible a sine wave, and for this purpose oscillograph records should be taken by the engineer.

It is important, especially in these competitive days, to see that the iron in the machines is not unfairly reduced in weight, or that too high a flux-density is used with consequently a too narrow margin for steadiness in running.

The copper can fairly well take care of itself, since the temperature guarantees will control the dimensions adopted. Hunting is sometimes found in reciprocating engine-driven sets owing either to an insufficient flywheel effect, with a consequent cyclic irregularity, or to over-sensitive engine governors. This effect is almost unknown with turbo-driven sets.

Surging of current between alternators also sometimes happens, and is due either initially to hunting, or to an insufficient amount of iron in the stator or rotor. An extra amount of iron acts as a damper on the oscillations. A damping coil or copper grid embedded in the pole faces will have the same effect, and may be used, or solid iron poles or cast-iron pole shoes, the latter providing an easy path for the eddy currents. These have the effect of damping down reactive currents which tend to make the machine unstable.

Inherent Regulation.—The inherent regulation of generators is another matter requiring attention when selecting machines. This is, of course, the percentage by which the voltage of a generator rises, with constant speed and excitation, when the rated load is suddenly thrown off. Manufacturers supply characteristic curves with their tenders, from which both this and the inherent regulation for varying power factors can be at once deduced. On non-inductive loads this is usually restricted to 6 per cent., and with a power factor of 0·8 restricted to a maximum of 20 per cent. The makers of salient pole rotors claim that a better regulation is obtained with this type, and that heavier overloads may be got due to the greater weight of copper possible to be carried on a rotor of any given dimensions.

Excitation regulation is another detail which requires to be specified by the engineer or stated by the manufacturer. This is the percentage increase at full load current above that for no-load,

by which the rated voltage of the generator may be maintained at the rated output in amperes.

Efficiency.—The efficiency of a machine is in good practice now generally specified as follows (according to the size of the machine):—

Power Factor Unity.				
$1\frac{1}{4}$ load.	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4}$
95·5–97%	95·5–96·5%	94·5–95·5%	93–93·6%	88·2–90%
Power Factor 0·8.				
94·5–96·7%	94·5–96·2%	93·5–95%	91·5–93·5%	88%

Heat Tests.—The temperature rise of any part of the generator, after twelve hours' full load run, at 0·8 power factor is usually specified not to exceed 39° C. (70° Fahr.) above that of the surrounding air when taken with a shielded mercury bulb thermometer encased in tinfoil, placed against any winding, or against the iron of the magnetic circuits.

The heat test on large machines is usually made at the makers' works by running each generator on open circuit, over-excited, until such time as the stator iron temperature is steady, which may be taken as the period when the increase in temperature does not exceed one-half a degree C. in one hour.

The permissible temperature rise under this condition is generally specified not to exceed 30° C. (54° Fahr.) taken as above.

Balancing Rotors.—The accurate balancing of rotors is of great importance. This is usually effected by first obtaining a stator balance on a pair of knife edges, and also by running up to a proof test speed about $\frac{1}{3}$ above normal speed in a special balancing machine. The two tests are essential, as while a rotor may have been built up with an accurate statical balance, displacement of parts may occur after running up to speed which will upset entirely the former accurate balance; so that a powerful couple may be set up and cause excessive vibration.

Direct Current Turbo Generators.—For direct current turbo generators some manufacturers now exclusively use compensated windings, generally concentrated on the pole pieces, of the order of twice to $2\frac{1}{2}$ times the ampere turns on the armature. These have the effect of neutralizing any distortion of the flux by the armature,

and they also provide a field to reduce sparking as the current in each particular coil is undergoing reversal, thus increasing the range of sparkless commutation. There is, however, a tendency to flash over owing to the excess field ampere turns, and it is now usual to adopt a combination of both compensating windings and intercalary poles.

Brushes and Commutators on Turbo Generators.—Some makers use brass wire brushes running on grooved commutators so as to increase the area of contact and to allow the brush to follow better any irregularities on the commutator.

Others adopt radial commutators with the brushes arranged sideways, so as to avoid jumping. Pneumatic holders for carbon brushes are also used, each has its advocates, but the radial type appears to be the best kind both mechanically and electrically.

Direct current generators are usually specified to have a temperature rise after a six hours' rated load run not exceeding 50° C. (equivalent to a rise of 90° Fahr.) above the surrounding air—the temperature being taken as mentioned under "Heat Tests" on p. 381.

The armature windings should consist of rigid former wound coils in one piece, without joint, embedded in and well insulated from rectangular slots in the armature core, held in position by hornbeam wedges, and capable of being easily removed and replaced. The core plates should be of soft annealed steel of high magnetic quality, and well insulated from each other. The windings should be wound from bare copper strap, each strap being taped with an overlapping layer of No. 2 cotton tape, the coil being then impregnated *in vacuo* with a clear baking varnish. The coil within the slot should be wound with so many turns (to suit the pressure) of pure manilla paper and mica interleaved between the copper straps. The whole coil should then be taped with an overlapping layer of No. 2 cotton on the ends (non-overlapping in the slot), and again vacuum impregnated. Equalizing rings should be placed at the back of the commutator.

Each coil should be tested at, say, 2000 volts alternating for one minute before being placed in position.

The pole pieces are better made of laminated steel with solid pole tips and accurately machined. The field coils should be

readily detachable, interchangeable and well ventilated. The connections between adjacent coils should be well secured to the rotor, connected by clamping sleeves and protected by insulating cases of leatheroid, for example.

The commutator hub should be cast with the armature spider, or so rigidly clamped to an extension that no relative movement between the two parts can take place.

The bars should be of hard drawn copper finished accurately to gauge, and insulated from each other with good amber mica milled carefully to a uniform thickness, and of such a quality as to wear evenly with the copper segments.

Ventilation of Generators.—The ventilation of machines is important, and has a direct effect on the rating of the machine especially in exacting climates, or in plants running on a high-load factor. In some cases a fan is fixed at each end of the rotor, the air being driven around the end windings of the stator and also through the ducts in the core plates and out at the top of the casing. This system is quite satisfactory for machines up to, say, 2000 K.V.A. For larger machines a separately driven fan should be provided, supplying air through trunks to the bed-plate inlets and forcing it through both rotor and stator, so that large quantities of air of the lowest available temperature can be forced through the generators. Machines so ventilated are capable of developing heavier overloads than when only self-ventilated. Where coal dust has to be considered, as in the case of collieries; or in climates subject to dust storms, or in large cities, air filters are sometimes employed, the air supplied to the machines being thoroughly cleaned and cooled.

At the Dock Sud power house, Buenos Aires, for example, the 7500 K.W. turbo generators are of the enclosed type with induced draught ventilation, on Brown Boveri's system, cold air entering through openings in the bed plate and then being blown by means of two fans through channels provided on the rotor and then through the stator, leaving the machine by an opening at the top of the casing. By means of this system of ventilation all parts of the machine are maintained at a uniform temperature, and equal expansion results.

These generators are capable of carrying a 25 per cent.

overload for half an hour, and the temperature rise on any part of the machine after 10 hours' continuous run at rated load was guaranteed not to exceed 50° C. (90° Fahr.) above that of the surrounding atmosphere.

Specification of Materials.—Very great care has of course to be exercised in the specification of the materials used on rotors, and the following notes will be useful.

The peripheral speed of turbine-driven rotors is usually about 17,000 feet per minute, but speeds of 21,000 are also adopted by manufacturers who claim an ample factor of safety.

Steel shafts should be machined down from heavy forgings of mild open hearth acid steel with a tensile strength of from 34 tons to 37·5 tons per square inch, and an elastic limit from 20 to 22·5 tons, with an elongation not less than 26 per cent. in a 2-inch test length.

Steel binding wire with a tensile strength of 112 tons per square inch should have a factor of safety of 3, taking into account both bending and tensile stresses.

Bronze binding wires with a tensile strength of 54 tons per square inch with a factor of safety of 3, taking into account both bending and tensile stresses.

Spiders for rotors should be strongly constructed and clean cast from a mixture of good grey close-grained pig iron. A test bar cast from the same mixture, 3 feet 6 inches long and 2 inches by 1 inch in area, placed on bearings 3 feet apart, should bear a test load of 30 cwt. suspended from the middle point without breaking, the deflection under this load not to be less than $\frac{5}{16}$ inch.

The laminations for the stator core and poles should be of best soft annealed steel, having a low hysteresis constant and a high permeability, and free from burrs on the edges. The core plates should be well insulated from each other.

Pole-pieces should be so designed as to permit of their easy removal with their field coils without dismantling any part of the stator. The pole tips should be so shaped as to distribute the flux in such a manner as to give practically a sine wave-form. Damping coils are sometimes required or other means adopted to improve parallel running.

Collecting rings for revolving fields are usually turned from hard gunmetal shrunk on a cast-iron bush previously insulated with a moulded mica ring. The brush current density, if carbon brushes are used (as is general), should not exceed 40 amperes per square inch.

Main bearings should be lined with white metal, which is usually made up of the following proportions, viz. 14·8 parts of antimony, 24 parts tin, 61 parts lead, with a trace of copper.

Excitation.—In some cases a direct-driven exciter, complete with the main set and driven from its shaft, is selected; in others, separately driven exciters supplying the whole plant. Overhung exciters should be fixed on a very substantial bracket or pedestal, so that there may be no vibration arising from any "whip" of the extended shaft. On the whole, a separate exciter to each set has recommendations, as simplifying the exciter cabling, and reducing the risks of breakdown. Having regard, however, to the additional uses of independently driven exciters for the lighting of the power house and the supply of the auxiliary motors, these are of value when coupled with a battery to give greater security in medium-size power houses.

For larger plants, however (that is, units of 5000 K.W. and upward), the condenser motors become so large that the total cost of the power house is sensibly increased if direct-current motors supplied from an independent source are applied, and it then becomes advisable to install polyphase motors. That being the case, an independent exciter is better fixed to or driven from each main generator.

Auxiliary Motors.—The auxiliary motors in power houses are required to drive condenser pumps, feed pumps, mechanical stokers, large and small fans, and so forth, and they represent a ratio to the total plant installed amounting to some $2\frac{1}{2}$ or 3 per cent. In 3-phase plant it is, perhaps, more economical to fix 3-phase auxiliary motors, though if a total failure of supply take place this may cause trouble with the condensers and turbines and loss of time in restarting the plant. With independent exciters and a reserve battery for excitation and lighting greater security will be found, therefore, in installing direct-current motors. Practice varies in this, but as no greater cost

is involved and greater security is obtained, there is much to be said for direct-current motors in power houses of medium size. If direct current is adopted, it is now customary to fix the standard pressure of 220 volts as being better applicable generally to excitation, lighting and auxiliary motors. Should 3-phase motors be determined upon, then a pressure of 500 volts between phases is usually selected, the motors being supplied through step-down transformers.

Nothing very much is required to be said here about motors. Except that in polyphase motors, those above 10 H.P. may be supplied with squirrel-cage rotors, and those above 10 H.P. should be of the slip-ring type, so as to reduce the starting current.

They are, by nature of their work, generally to be rated as "continuously working," and they should be specified to run at rated load for six hours without the rise of temperature exceeding 40° C. (72° Fahr.) above the surrounding atmosphere. They also should be capable of a 50 per cent. overload for 30 minutes without a rise of temperature exceeding 50° C. (90° Fahr.). It is better to have all motors in the boiler house of the enclosed type, and elsewhere of the protected type. Interchangeability of parts should be insisted on, as this will reduce the number of spare parts carried. The number of sizes of motors themselves should also be reduced to a minimum within reasonable limits, thus reducing the number of spare armatures or rotors required.

It may be well to state here, rather than under Switchgear, that the Author has found it advisable, in a power house layout, to control all motor circuits from one main (auxiliary motor) board, taking cables therefrom to the various motors, each of which has its separate switch and set of fuses (or with polyphase motors, auto-transformer or starting switch, either of the rheostatic or tramway controller type). Automatic lubrication is of course always provided.

Boosters.—Where a battery is adopted, a motor-driven booster is indispensable. The object of this machine is of course to compensate for the variation of voltage between the extremes of charge and discharge, and results in a minimum number of cells installed. Care must be exercised to see that such a machine is amply big enough to take the larger current from the battery

on emergency (short-time) discharges. "Milking" boosters are also required so as to doctor a weak cell. Series boosters are also sometimes adopted in direct-current plants to compensate for the loss on long feeders, and are cheaper in some cases than the extra amount of copper otherwise required in the feeder. They may also eliminate the necessity for duplicate bus bars on the main switchboard, and the running of two sets of machines at lower plant-load-factors than when the whole supply is grouped on one bar.

Battery boosters may be classed as under:—

1. Simple hand regulated shunt boosters.
2. Constant current, non-reversible, automatic boosters.
3. Differential, reversible, automatic boosters.

The first type is not to be recommended except in small power houses, where the attendant is continually on the switchboard and is only lightly worked. The function of this type of booster is to compensate for the difference in voltage between the bus bars and the increasing voltage of the battery during charge, or a voltage range equivalent to the number of cells in series by 0·7 volt (*i.e.* the difference between charge and discharge voltage, 2·55 and 1·85 respectively).

By the use of a two-way switch on the board the booster can be used for discharging the battery, and to compensate for the difference between the bus bar voltage and the diminishing voltage of the battery as it is discharged to its minimum limit. The booster must therefore be able to carry the maximum battery current (at a one-hour rate) for one hour and an emergency current of 50 per cent. over one-hour rate for several minutes, within the usual guaranteed temperature limits.

Non-reversible Automatic Boosters.—The non-reversible automatic booster is used for general supply work where the load fluctuates rapidly, and the battery is thus able automatically to follow the variations in the external load and to keep the machines on circuit on constant load. It is compound wound, with a stronger shunt field wound in opposition to the series field; the line current passing through the booster armature and series coil in series.

Reversible Automatic Booster.—The reversible booster has its

armature in series with the battery (both in parallel to the external line) and the series coil in series with the line, the shunt being of course in parallel to the line. It thus carries current in both directions, passing the maximum battery current through its armature, the maximum voltage being coincident with the maximum output. This type is used for traction purposes in situations where the external load is large, and where the battery charge and discharge rates are moderate, and where the voltage must be maintained during any increase of external load. There are several variations in the applications of automatic boosters, and the Entz booster may be described as a type.

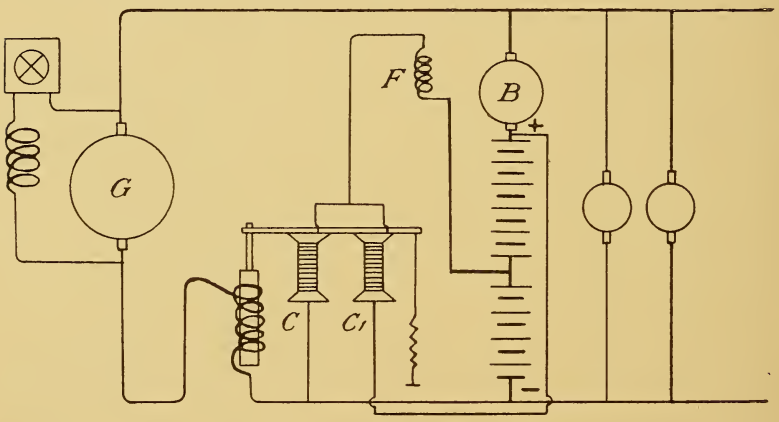


Fig. 166.

The diagram of connections is shown in Fig. 166. The booster field winding, F, is connected at one end to the middle point of the battery, and the other end to the upper contacts of two carbon resistances, C and C_1. The lower end of the carbon resistance C is connected to the negative side of the battery. The corresponding end of C is connected to the positive end of the battery. If the resistance of C is equal to that of C_1, there is no potential difference across F. The potential drop through C, C_1 is equal to the total battery pressure. If resistance of C = resistance of C_1, the drop from either side of the battery through C, or C_1, is one-half the total drop. Therefore the end of the field winding F is also at the same potential as the middle point of the battery,

as is also the potential of the other side of the winding F. Therefore there is no current through F. If, however, any inequality of these resistances is obtained, then there will be current in F, and its direction will depend on which of the resistances is less, its magnitude being proportional to the difference between the two resistances. Variation of the pressure on the carbon pile causes variation in its resistance and in the magnet M, which is opposed by the spring S. Both pull on lever L, which rests on the carbon piles C and C_1, controlling the relative resistances of the two, and so cause either charge or discharge of the battery. The magnet M is in series with the generator current, and when the load is normal the spring pull is adjusted so as to be just equal to the magnet pull, and the resistances of C and C_1 are thus equal. When the external load varies, a small but proportional variation in the pull of S changes the relative resistances in the carbon piles C and C_1, and the booster field is thus energized so as to produce a booster pressure, causing the battery either to charge or discharge.

As an example of the cost of reversible automatic boosters, the following example may be cited.

A booster guaranteed to meet the following conditions:

(*a*) 1000 amperes from 0–100 volts continuously,
(*b*) 630 „ „ 0–200 „ „
(*c*) 1600 „ „ 0–120 „ on emergency for three minutes,

would cost £825, or £6·5 per K.W. normal rating, and £4·3 per K.W. overload rating.

Balancing Transformers.—Balancing transformers are also required in direct common power plants supplying a 3-wire system so as to compensate for want of balance between the current in the + and − sides of the middle wire. These consist simply of a motor connected across the outers and driving two small shunt-wound generators all on one shaft, each generator being connected to its own side of the 3-wire system. To determine the size of the balancer the greatest possible difference between the currents in the outer conductors at any one time must be estimated. As a matter of practice, even in quite large

systems an out-of-balance current of 250 amperes is an extreme figure, since all but the smallest motors on the supply system are connected across the outers, while the lighting loads equate out in a remarkable degree. A battery in such systems is also a standby for balancing purposes.

Variable Speed Motors.—Variable speed motors are often required for mechanical draft and for air or feed pumps. With direct-current motors variation of speed can be efficiently arrived at in large machines by adopting a double-wound armature with a series-parallel control, as in the case of large fans; or with polyphase motors within a strictly limited range, by rotor resistances.

Portable "Blowers."—Portable motor blowers are necessary for removing dust from windings, etc., the air pressure is about 30 lbs. per square inch, so that internal windings can be cleared of dust without difficulty. It has been sometimes said that pressure cleaners of this kind only blow the dust from one spot so that it settles in another. The Author has not found this so in practice, and the machines are most useful and efficient. The alternative vacuum cleaners, it is said, have the disadvantage of sucking away some of the fibrous material of the insulating layers as well as the dust, though this criticism can hardly be said to be a fair one. One or other of these dust removers is, however, a useful auxiliary.

Static Transformers.—Transformers in alternating current power houses are required for lighting or auxiliary motors, as well as for stepping up the bar pressure to line pressure in special cases.

Three-phase oil-cooled transformers are usually used in which the primary may either be $\triangle$ or star wound, and the secondary star wound. For auxiliary motors the secondary pressure between phases is usually 500 volts, and for power house lighting 220 volts.

Three classes are recognized by the British Engineering Standards Committee, viz.—

(1) Air cooled by natural draught.

(2) Oil cooled by immersion.

(3) Artificially cooled, including both types as above.

There are also, of course, water-cased transformers which are sometimes used for step-up purposes, and in large sizes.

The standard sizes made—*i.e.* the loads at which the transformers will work continuously, while conforming to the standard tests given below—are:

5, 7½, 10, 15, 20, 30, 40, 50, 75, 100, 150, 200, 250, 300, 400, and 500 K.V.A.

The highest mean temperature permissible for both types, in which linen, cotton, paper and its preparations, micanite, or similar insulating materials are employed, is 176° Fahr. (80° C.).

It is unnecessary, in this work, to say much more on this head, as one is not dealing with transformer design, but rather with the useful application of them in power houses. It will suffice to say that the load should be specified in Kilovolt-amperes, and that each transformer should be capable of working continuously at rated load, with a temperature never exceeding 40° C. (72° Fahr.) above the surrounding atmosphere; and three hours at 25 per cent. overload without a greater temperature than 50° C. (90° Fahr.). The temperature rise being measured by a thermo-couple placed in the oil against the core.

Each transformer should be tested also between the H.P. and L.P. windings, and between the L.P. windings and frame, by twice the working voltage, for a period of 15 minutes.

The efficiencies of transformers are generally as follows:—

Power factor.	25% overload.	Rated load.	¾ load.	½ load.	¼ load.
1·0	98%	98·1%	98·1%	97·8%	96·5%
0·8	97·5%	97·6%	97·6%	97·2%	95·6%

the efficiencies being calculated from separate measurements of core and copper losses at a temperature of 60° C. (108° F.).

The transformer should be fitted with radiating gills or corrugations to give effective radiation of heat, eye-bolts for lifting, and sometimes rollers, outside shielded terminals, and oil-level indicators and cocks.

Low tension secondary tappings will be found useful so that the voltage may be varied from time to time, according to the ruling H.T. bar voltage at the main switchboard.

The oil must be carefully chosen, and must be free from moisture, acids, alkalies, and sulphur compounds having a high

dielectric strength, and with a flash point over 180° C., as previously described.

Table No. CXV. sets out the leading dimensions, weight, etc., of standard sizes of transformers for 50 ~.

TABLE CXV.

Output K.V.A.	Quantity of oil. Gallons.	Approximate net weight. lbs.	Dimensions.		
			Height.	Width.	Length.
			ft. ins.	ft. ins.	ft. ins.
2	3	195	1 5	0 7	1 4
5	7·5	495	2 0	0 9¾	1 7
7·5	7	550	2 5	0 10½	1 9½
10	18	750	2 5	0 10½	1 9½
15	27	1000	2 11	1 5½	2 4
20	26	1060	3 5	1 9	2 3
25	35	1280	3 5	1 9	2 3
30	34	1350	3 7	1 9	2 4
37·5	40	1470	3 7	1 9	2 4
50	48	1600	4 0	1 10	2 5

Transformers vary in cost from about £2 per K.V.A. for sizes up to 10 K.V.A. to £0·75 per K.V.A. for transformers of 250-K.V.A. output, and £0·64 per K.V.A. for sizes of 500 K.V.A.

In cases of difficult transportation, 3-phase line transformers may be replaced by three single-phase transformers with advantage, so as to reduce the weight of individual pieces to be carried.

Batteries.—In alternating current-power houses, the battery is useful as a reserve for excitation and for power-house lighting purposes. In direct-current plant they are useful for reserve purposes, and are sometimes of very large output, and incidentally for balancing the loads on a 3-wire system. For traction purposes, with a very fluctuating load on the generator, they are often a great economy. Even in a general supply system, where 3-phase energy is transmitted to substations and there converted to direct current for distribution, batteries play a most useful part, not only in securing a larger measure of safety, but in a resultant economy by improving the load factor. The Planté plate is now practically universally used. And though no other elements but lead and its oxides have been yet found commercially practicable, great commercial progress has been made in

recent years in the application of batteries to electrical supply on a large scale, and in reducing the initial cost and cost of maintenance, as well as improving the efficiency and practical reliability of the cell.

Within usual rate limits, from 0·5 to 0·8 oz. of spongy lead, and from 0·53 to 0·86 oz. of metallic lead changed to peroxide, are required in negative and positive plates respectively to give a discharge of one ampere-hour.

The storage capacity of batteries depends, of course, on the rate of discharge and the temperature, besides, of course, being dependent on the size and character of plates and their number. The effect of *rate of discharge* in Planté plates is shown in Table No. CXVI.

TABLE CXVI.

Time of discharge in hours.	Percentage of capacity at 8 hours' rate.
	per cent.
8	100
6	96
4	80
2	60
1	56

As a datum for Table No. CXVI. it may generally be taken that with an 8 hours discharge and at a temperature of 60° Fahr. from 40 to 60 amperes per square foot of *positive* plate surface can be obtained, *i.e.* the number of positive plates in parallel in one cell × breadth × height × 2.

The energy output in watts is usually about 7 watts per pound. The charge and discharge rate per square foot of *positive* plate under normal working conditions may be taken at 10 amperes.

Planté plates are now wholly used for heavy power house work, the active materials being of course formed out of and on the surfaces of the lead plates themselves. As the electrolytic action on the active material rarely penetrates to a greater depth than $\frac{1}{16}$ inch, the plates are made up of lead grids subdivided in such a way as to give a maximum working surface in any given size of plate.

Particular care must be taken with batteries to get pure

sulphuric acid made from sulphur and not from pyrites. The latter, of course, contains iron, and acid made from it contains traces of iron. The electrolyte must be free from iron, or arsenic, copper, chlorine, nitrates, mercury, acetic acid, selenium, and other chemicals, the slight presence of which would be injurious to the working of the battery and to the life of the plates. Commercially pure acid with a sp. gr. of 1·84 should therefore be obtained, corresponding to a strength of 97 per cent. The engineer should insist on a certified analysis being supplied, especially for the first setting up.

The Author usually specifies that not more than the following percentages shall be found on analysis, viz. :—

Iron, 0·005 per cent.

Chlorine, 0·002 per cent.

Nitrogen (in 0·005 per cent., any form).

Particular care must also be taken with the water used to make up the electrolyte, not only when first setting up the cells, but also for make-up purposes afterwards. It is better to use distilled water, and in large batteries a distilling plant is a necessary auxiliary to be installed. In large batteries the Author thinks it would be well to fix circulating arrangements, so that the heavier layers of electrolyte which tend to collect in the bottoms of the cells may be circulated from time to time with the overlying lighter layers. "Gassing" the cells, while causing a fair circulation, does not necessarily bring up the denser electrolyte from the bottom layer. What has to be aimed at is a uniform density of electrolyte throughout the cell, so that uniform discharge rate per unit area of plate may result. Not only the density of the electrolyte but also the temperature affects the resistance. The density decreases with the discharge and also with an increase of temperature, amounting to 0·0032 per degree Fahr.

Plates deteriorate rapidly if worked at temperatures above 100° Fahr., which should be the maximum temperature permissible. In hot climates, therefore, it is necessary to take special precautions for the ventilation of the battery house and to screen the roof from direct absorption of the sun's rays.

The efficiency of cells expressed in ampere hours is 90 per cent., and expressed in percentage of energy output to input

from 75 per cent. to 80 per cent. taken at a normal 4-hour discharge.

Wooden tanks (teak is preferable) lead lined, with the joints autogenously welded are invariably adopted in power house practice, the wood being dovetailed and pinned together with antimony-lead dowels. The lead sheeting should be turned well over the edges of the wood box, so as to prevent the acid creeping

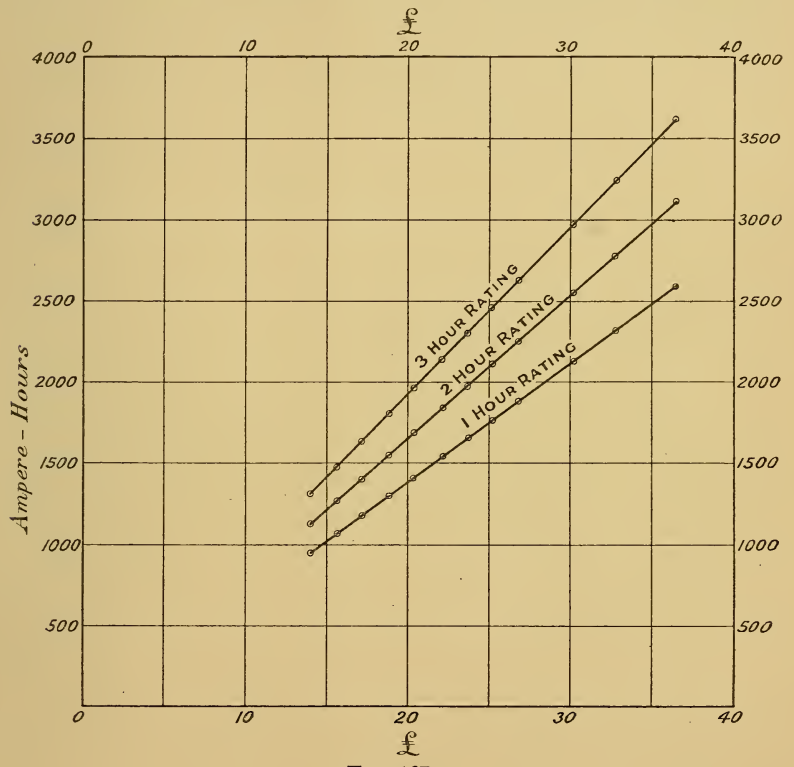


FIG. 167.

between the lining and the box. Solid lead boxes strengthened with antimony-lead ribs are also supplied. These are somewhat more costly than lead-lined wood boxes. The respective plates of each cell and its neighbour welded up to a lead bus bar fixed between them. Glass tube separators between the plates are best, enabling easier inspection of the plates for scale, etc., with the special lamp, and freer circulation of the electrolyte.

The cells are carried on heavy insulators fixed either directly on the battery house floor or on H joists carefully coated (and maintained) with anti-acid enamel.

The following Table, No. CXVII., sets out typical sets of cells suitable for power house work and for substations. Of course, very much larger (or smaller) sets are made, and the designer can obtain particulars of these from any of the well-known manufacturers.

TABLE CXVII.

HIGH WORKING RATE CELLS.

No. of plates.	Ampere hours.	Working rates. Discharge. hours.	Discharge. amperes.	Charge. amperes.	Weight of cell complete with acid.	Gallons of dilute acid.	Dimension of cell. Length.	Width.	Height.
					lbs.		ins.	ins.	ins.
17	1314	3	438	480	1100	35	21	$23\frac{3}{4}$	$38\frac{1}{2}$
	1128	2	564						
	943	1	943						
21	1644	3	548	600	1300	43	25	$23\frac{3}{4}$	$38\frac{1}{2}$
	1410	2	705						
	1178	1	1178						
25	1971	3	657	720	1510	51	29	$23\frac{3}{4}$	$38\frac{1}{2}$
	1692	2	846						
	1414	1	1414						
29	2301	3	767	840	1720	59	33	$23\frac{3}{4}$	$38\frac{1}{2}$
	1976	2	988						
	1649	1	1649						
33	2628	3	876	960	1940	67	37	$23\frac{3}{4}$	$38\frac{1}{2}$
	2258	2	1129						
	1885	1	1885						
37	2958	3	986	1080	2150	74	41	$23\frac{3}{4}$	$38\frac{1}{2}$
	2539	2	1270						
	2121	1	2121						
41	3285	3	1095	1200	2360	82	45	$23\frac{3}{4}$	$38\frac{1}{2}$
	2822	2	1411						
	2356	1	2356						
45	3615	3	1205	1320	2570	90	49	$23\frac{3}{4}$	$38\frac{1}{2}$
	3103	2	1552						
	2592	1	2592						

It is not relevant to the objects of this book to enter into the question of the chemical theory or practical treatment of the battery, except so far as to recommend the necessary equipment to enable the staff to maintain the battery properly.

Certain of the cells will lag behind others from time to time and become "sick"; to meet this trouble, it is necessary to supply "milking boosters" which can be attached to any sick cell either to give it an increased charge after the remainder of the battery has been fully charged, or to assist it in parallel during the period of discharge. These auxiliaries are absolutely necessary. In a large battery equipment the Author stretches two bare trolley wires over each line of cells suspended on insulators and strained at both ends on shackles. To each pair of these conductors a milking booster fixed in an annexe to the battery house complete with its auxiliary switchboard supplies current available for any one (or two cells in series). Generally speaking, one "milker" to each line is quite sufficient. In smaller batteries an equipment of two milkers only is quite enough.

The old method of regulating end cells of a battery has quite gone out; for heavy discharges not only was the switch very cumbersome and expensive, as well as the copper connections from each regulating cell, but also the rate of depreciation on the end cells, which were not worked so much as the others and tended to become overcharged and "fallow," was very high.

The regulation of a battery voltage to suit the bar or line voltages is now always effected by a battery booster. The reader is referred for further particulars to the paragraphs on battery boosters (*ante*).

The battery should be provided not only with hydrometers and thermometers, but also with a recording voltmeter, which will prove a useful indicator to the power house superintendent as to use or misuse of the battery.

In laying out the battery and designing the battery room, double tier stands must be avoided. Cells should be arranged on one tier only, so as to be easily inspected and handled. It is customary to support cells on very large porcelain cup insulators with oil, so as completely to insulate the cell from earth.

The battery room floor must be designed to carry a heavy concentrated weight, reaching as high as 1½ cwt. per square foot (excluding weight of floor). If on the ground-level stable blue Staffordshire paving bricks cannot be beaten, as they are vitreous and acid resisting, checkered on the face so that spilt acid or drip

from condensation drains away clear of the tread of the floor, and they can be laid in neat courses with thin (cement) joints. They should always be laid with a good gradient, usually $\frac{1}{100}$ to gullies, enabling the floor to be readily washed down and to dry quickly.

The walls are best lined with glazed brick, and very adequate ventilation of the room should be provided so as to get rid of the acid fumes. An annexe screened from the actual battery room should be provided to house the milking boosters and auxiliary switchboards. As stated before, the milking leads are best provided by stretching two trolley wires lengthwise with each line of cells fed by the milking booster, and to which faulty cells can be connected.

Ample storage room for acid should be given, and in some cases a separate accommodation for a water-distilling plant and storage tank.

The approximate capital costs of batteries is given in Fig. 167 (p. 395) for various discharge rates.

CHAPTER XII

SMALL POWER HOUSES AND SUBSTATIONS FOR SHIPYARDS, FACTORIES, DOCKS, ETC.

An engineer is often called upon to determine whether more economy or less is to be gained from installing an independent power house, driven either by steam or gas or oil engines, to supply the needs of some factory or shipyard or other works; or whether a supply shall be made from some public authority to a substation erected on the works in question. It must not be overlooked that in many works shavings and other combustible refuse have to be disposed of and may represent a considerable proportion of the total fuel used. The Author somewhat fully dealt with this question in his paper on "The Supply of Electricity for Industrial Purposes," read before the Institute of Electrical Engineers in 1908. In this and the ensuing discussion the matter was fully threshed out. The whole question is dependent on the relative costs of supply from these alternative sources. It was shown (and was not disputed) that the relative costs of supply of small independent power plants measured at the power-house switchboard were generally as shown in Table CXVIII.

The following table sets out the ascertained cost of power per unit generated for small independent power houses from 100 to 500 H.P.

Producer gas is based on anthracite at 22*s.* per ton, or bituminous coal at 10*s.* per ton ; oil (petroleum residue) taken at 42*s.* per ton ; water for cooling purposes or boiler feed, 6*d.* per 1000 gallons ; repairs and lubricating oils and stores are taken from actual cases ; and depreciation and interest on capital are taken at 10 per cent., as is the usual practice in factories.

TABLE CXVIII.

Annual load factor.	Producer gas.	Oil.	Steam.	Average.
Per cent.	*d.*	*d.*	*d.*	*d.*
10	1·273	1·007	1·086	1·122
15	0·944	0·778	0·811	0·844
20	0·760	0·656	0·673	0·696
25	0·670	0·584	0·590	0·615
30	0·596	0·536	0·534	0·555
35	0·540	0·498	0·494	0·511
40	0·502	0·469	0·464	0·478
50	0·447	0·430	0·421	0·433
60	0·406	0·404	0·393	0·401

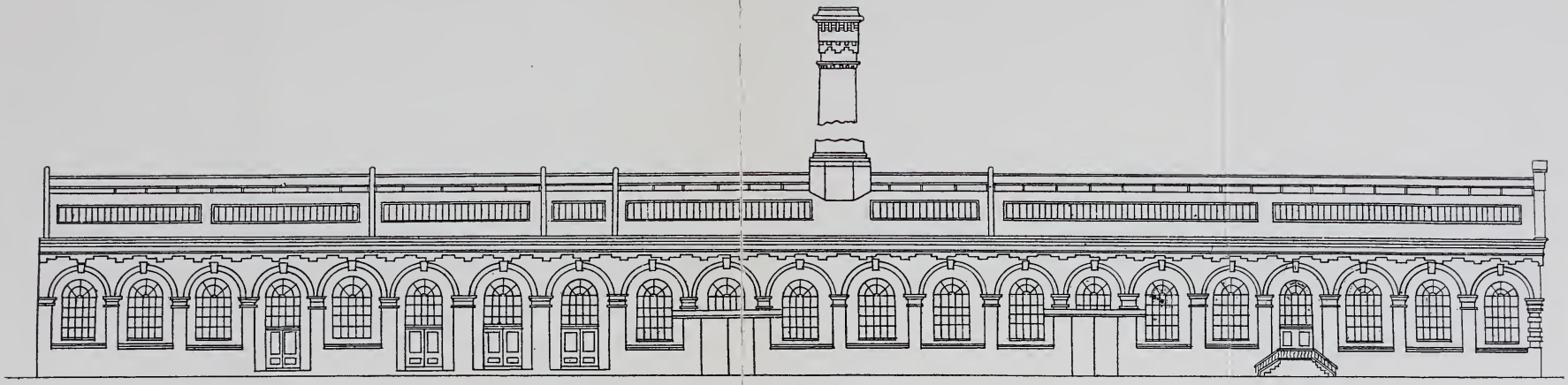
These figures refer to conditions in Great Britain, but the proportions will hold good for other countries.

A few typical small power houses and substations may be briefly given for reference.

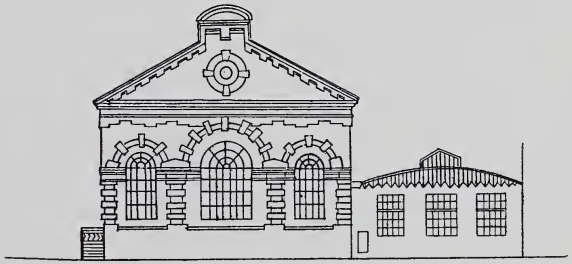
Shipyards: Independent Power House.—A plan and elevation of the power house at the big shipyards of Messrs. Harland & Wolff are shown in Plate No. XVII. There is a total of 4300 K.W. contained within a red-brick building 415 feet by 68 feet wide; representing 7 square feet per K.W. installed; or 380 cubic feet of building. There are five marine boilers, 200 lbs. working pressure, and each with 2225 square feet H.S. and two marine type water-tube boilers, each of 2115 square feet H.S. The shaft is 180 feet in height by 8 feet internal diameter at the cap.

The engine house shown in Fig. 166 is 168 feet by 62 feet wide, lined throughout with glazed bricks, the roof is heavily glazed, and there are also numerous wall windows. There are four Sulzer-Lahmeyer four-cylinder twin-tandem triple-expansion horizontal sets, 100 R.P.M., two of which have each a normal output of 1000 K.W. at 460 volts, and two of 650 K.W. each. There is also a sixth Allen set of 350 K.W. rated output, as well as a complement of exciters, battery boosters, and motor generators.

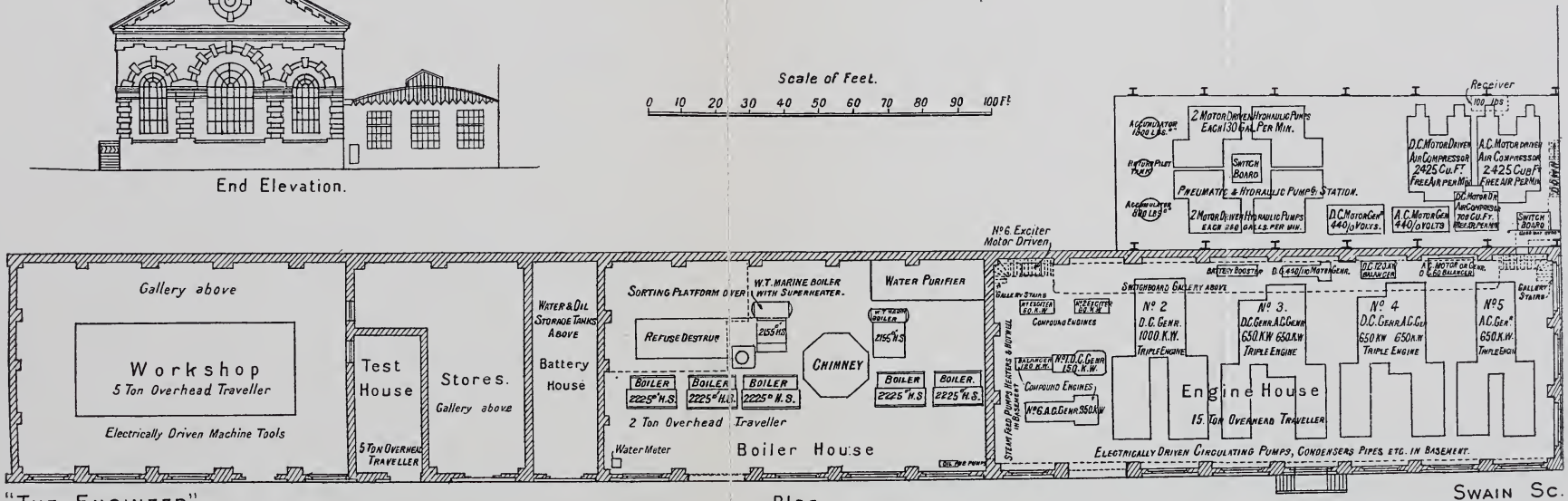
Shipyard Substation.—A typical shipyard substation containing four 250-K.W. synchronous motor generators may be described. The motors are 5500 volts, and the generators compound wound for 240 to 260 volts, each supplied with a direct-coupled starting



Side Elevation



End Elevation.


Scale of Feet.
0 10 20 30 40 50 60 70 80 90 100 Ft
Receiver
100 lbs
2 Motor Driven Hydraulic Pumps Each 130 Gal. Per Min.
Switch Board
Pneumatic & Hydraulic Pumps Station.
2 Motor Driven Hydraulic Pumps Each 280 Gals. per Min.
D.C. Motor Driven Air Compressor 2425 Cub. Ft. Free Air per Min.
A.C. Motor Driven Air Compressor 2425 Cub. Ft. Free Air per Min.
D.C. Motor Driven Air Compressor 700 Cu. Ft. Free Air per Min.
D.C. Motor Gen. 440/0 Volts
A.C. Motor Gen. 440/0 Volts
No 6. Exciter Motor Driven
Switchboard Gallery above
No 2 D.C. Gen.r 1000 K.W. Triple Engine
No 3. D.C. Gen.r A.C. Gen.r 650 K.W. 650 K.W. Triple Engine
No 4 D.C. Gen.r A.C. Gen.r 650 K.W. 650 K.W. Triple Engine
No 5 A.C. Gen.r 650 K.W. Triple Engin
Engine House
15 Ton Overhead Traveller
Electrically Driven Circulating Pumps, Condensers Pipes etc. in Basement.
Gallery above
Workshop
5 Ton Overhead Traveller
Electrically Driven Machine Tools
Test House
5 Ton Overhead Traveller
Stores.
Gallery above
Water & Oil Storage Tanks Above
Battery House
Sorting Platform over
W.T. Marine Boiler with Superheater.
Water Purifier
Refuse Destrue
Chimney
Boiler 2225 sq. ft. H.S.
2 Ton Overhead Traveller
Water Meter
Boiler House

Plan.

"The Engineer"

Swain Sc.

Plate XVII.—Messrs. Harland & Wolf's Power House.

[*To face page* 400.

motor which is roughly about 25 K.W. The floor space occupied per K.W. is 1·25 square feet, and the cubic contents 32 cubic feet per K.W.; the total cost of the substation, including buildings, plant, high and low tension switchboards, £6 per K.W. It may be interesting to note that the average ratio of the yearly input to output is 76 per cent., the average load factor being 35 per cent. and power factor about 0·95.

Tramways and City Substation.—Fig. 168 shows a typical substation designed for the Manchester Corporation for the tramways

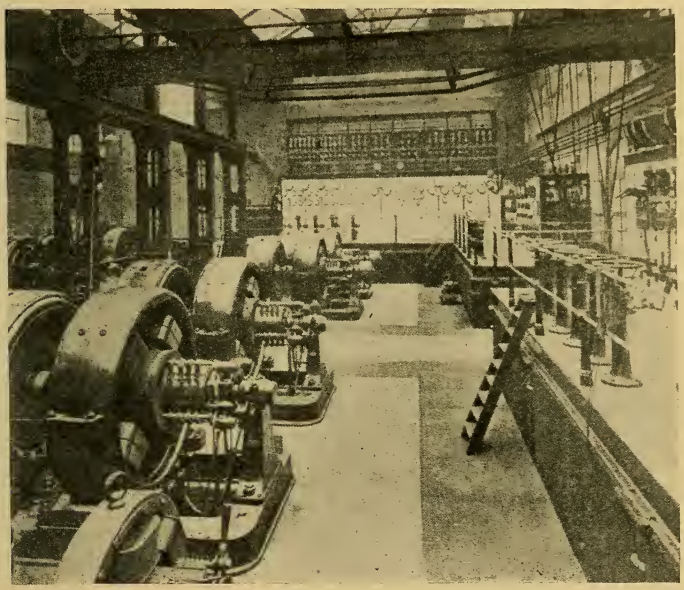


Fig. 168.

supply and for the general city supply. The floor space occupied is 22 square feet per K.W. and the cubic contents 80 cubic feet per K.W.

Collieries Independent Power House.—Fig. 169 shows a plan of the power plant at the Cambrian Collieries, Glamorganshire, South Wales. There are four Lancashire boilers, each 30 feet by 9 feet diameter, 160 lbs. working pressure, and a Green's economizer; two twin-feed pumps, each with a duty of 3000 gallons per hour.

The engine room contains three 1000-K.V.A. Belliss-Siemens alternators 250 R.P.M., 2200 volts 25 cycles per second (continuous rating 750 K.W. at 0·75 power factor). Korting ejector condensers are supplied. The floor space is 4·34 square feet per K.W. installed.

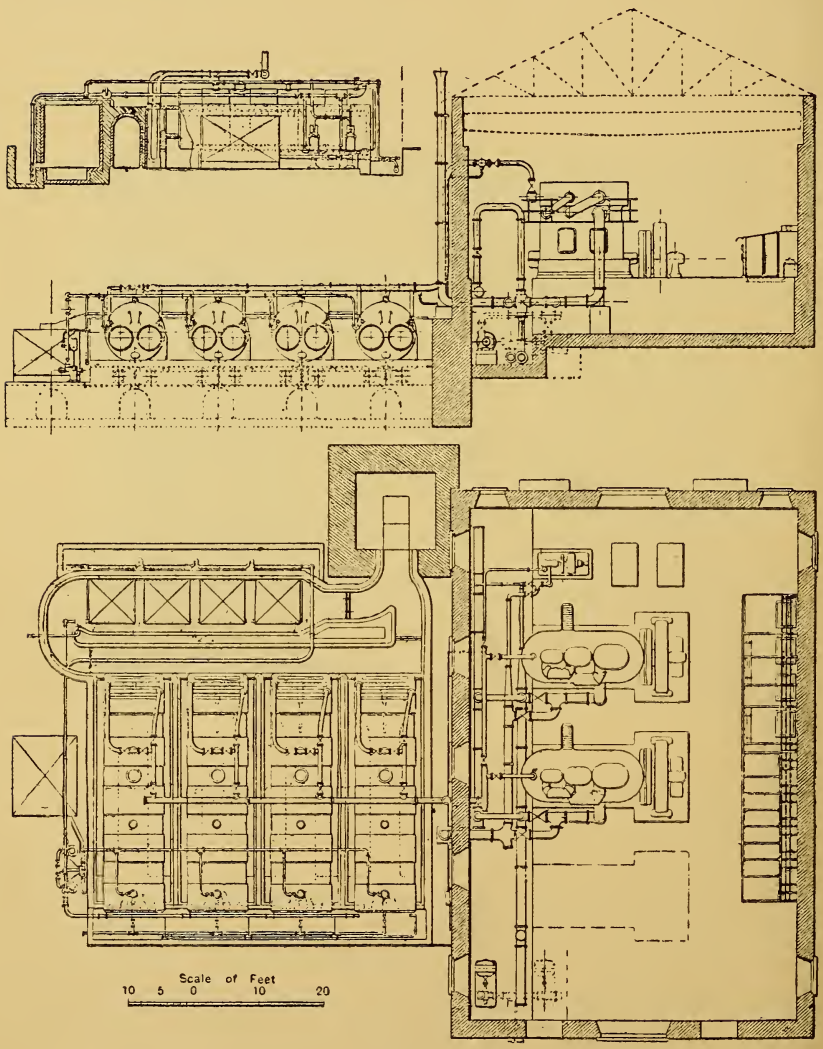


Fig. 169.

Small Rolling Mill Substation.—Fig. 170 shows a typical static substation for the supply of a small rolling mill, controlling one 500-K.V.A., two 300-K.V.A., and three 150-K.V.A. static transformers, from which the three rolling mill motors, one of 400 B.H.P. and two of 250 B.H.P. as well as forty-one smaller motors, ranging from 3 to 50 B.H.P., and aggregating 672 B.H.P. are driven.

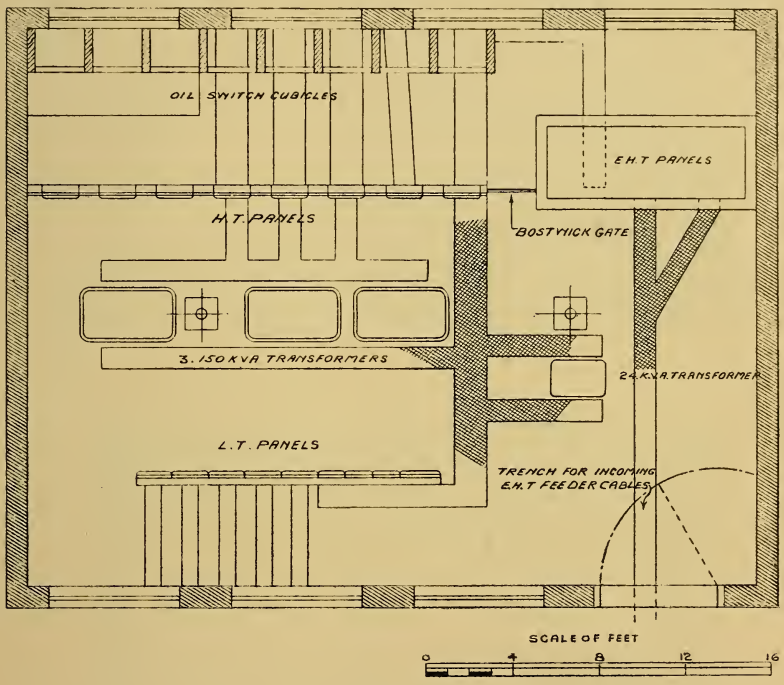


FIG. 170.

There is a H.T. switchboard to control the 5500-volt feeders and primary circuits, built on the wall cubicle system, and a low tension 3-phase (440 volts between phases) to control the works power circuits and the lighting circuits. Accommodation is also given to the Power Supply Authority's own board. In this case an existing building was adapted as a substation with very little reconstruction. The floor space occupied by the switchgear and three 150-K.V.A. transformers only is 1000 square feet, and the cost of the substation (excluding the cost of the substation

building) £1396, representing a cost of £36 per K.W. of transformers installed, including switch gear for the mill motors.

Docks Independent Power House.—A typical direct-current dock power house is shown in Figs. 171 and 171A. This is a power house

FIG. 171.

FIG. 171A.

designed by Messrs. Dixon and Baxter for the Rothesay Docks, belonging to the Clyde Navigation Trustees. The building shafts are of red brick. The plant at present installed comprises two water-tube boilers, each evaporating 1250 lbs. per hour, and two specially arranged 250-K.W. triple-expansion steam generators

as well as a third 120 K.W. set for night loads. The steam sets are specially arranged with a very heavy fly-wheel, which, together with two coal-hoist generators, is connected to the main shaft by a special flexible coupling. Supply is given to electrically driven coal hoists, turn-tables, jib cranes, capstans and dock lighting, with an output of some 1,500,000 units per annum, and a maximum load of 500 K.W. on the bars. The total floor space occupied (including engineer's office) will be about 2·5 square feet per K.W., and the capital cost about £25 per K.W.

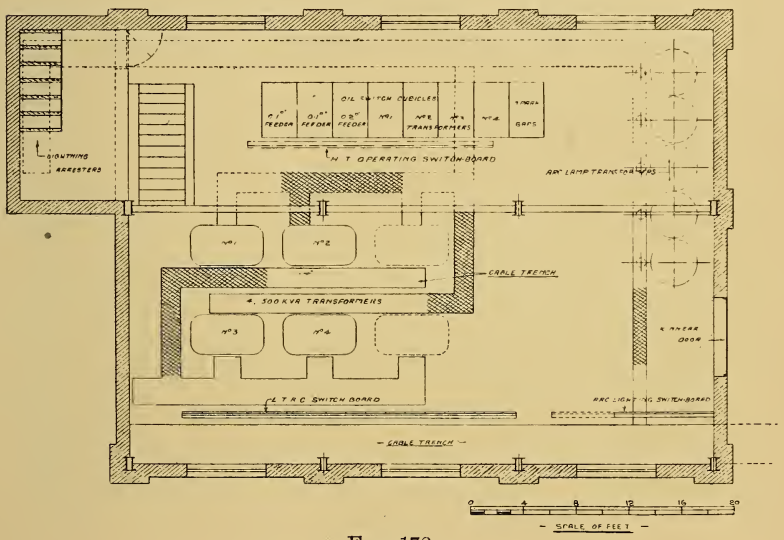


FIG. 172.

Docks Substation.—A typical 3-phase dock substation is shown in Fig. 172. This represents a substation designed by the Author for the supply of the Buenos Ayres and Pacific Railways Docks at Bahia Blanca, Argentina. It contains six 500-K.V.A. static transformers, a H.T. board to control the 5500-volt feeders and primary circuits, and also a low tension 3-phase power and lighting board. The H.T. switchgear comprises an operating panel on station floor-level, and the switch cubicles on the gallery floor above as shown in Fig. 173.

The switchgear provided includes—

(*a*) Three incoming feeder panels.

(*b*) Four H.T. transformer panels.

Each feeder panel is provided with the following instruments :—

(1) A loose handle with trip coil to control the oil-break switch.

(2) Ammeter on one phase with series transformer.

(3) Three-phase reverse current relay.

(4) 5000–8000 volts recording voltmeter.

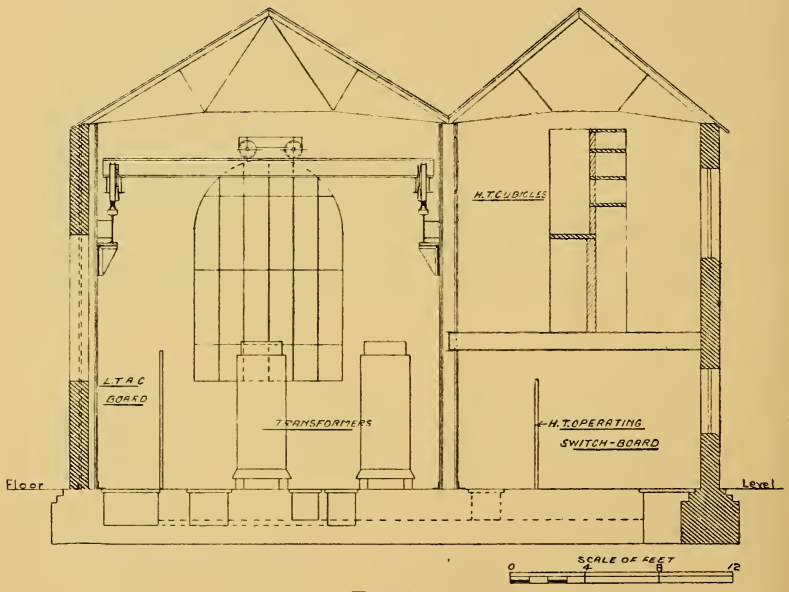


FIG. 173.

(5) Three isolating switches between each incoming feeder and circuit breaker (oil switch).

(6) Three isolating switches between each circuit breaker and the bus bar.

Each transformer panel is provided with—

(1) A loose handle with trip coil to control the oil-break switch.

(2) Ammeter on one phase with series transformer.

(3) Overload time limit relay with range of current adjustment and a time limit of 5 to 3 seconds.

(4) 14-inch dial voltmeter (5000–8000 volts) with potential transformer.

(5) Three isolating switches between the oil-break transformer switch and the bus bars.

The L.T. switchboard is situated at substation level and contains 11 panels, 4 for the transformer-secondaries, 6 feeder panels, and 1 arc lighting constant current transformer panel. The instruments provided are as follows :—

Transformer Panels (L.T.) :

(1) One automatic oil-break switch mounted on back of the panel, with loose handle.

(2) Ammeter on one phase, with series transformer.

(3) Recording voltmeter (on one panel only).

(4) 14-inch illuminated dial voltmeter, with potential transformer.

(5) Three isolating switches between L.T. bus bars and L.T. oil-immersed switch.

(6) Power-factor indicator.

Feeder Panels (L.T.) :

(1) Automatic oil-break switch with loose handle.

(2) Three ammeters, one on each phase, complete with series transformers.

(3) Three isolating switches between L.T. bus bars and oil-break switch.

(4) Three-phase integrating watt-hour meter.

Arc Lighting Panel :

(1) Three automatic single-phase oil-break switches mounted on back of panel with loose handles, and each provided with trip coils and series transformers.

(2) Three ammeters, one on each phase, and provided with series transformers.

(3) Three single-phase watt-hour meters, with instrument transformer.

There is a five-ton overhead crane.

The building is a steel skeleton structure with brick fillings and eternit sheet roofing. The floor space occupied is 0·6 square foot per K.V.A. installed, the cubic contents 15·6 cubic feet per K.V.A., and the cost complete with equipment £3·08 per K.V.A., of which the buildings represent £1·29.

The power supplied from this substation comprises jib cranes,

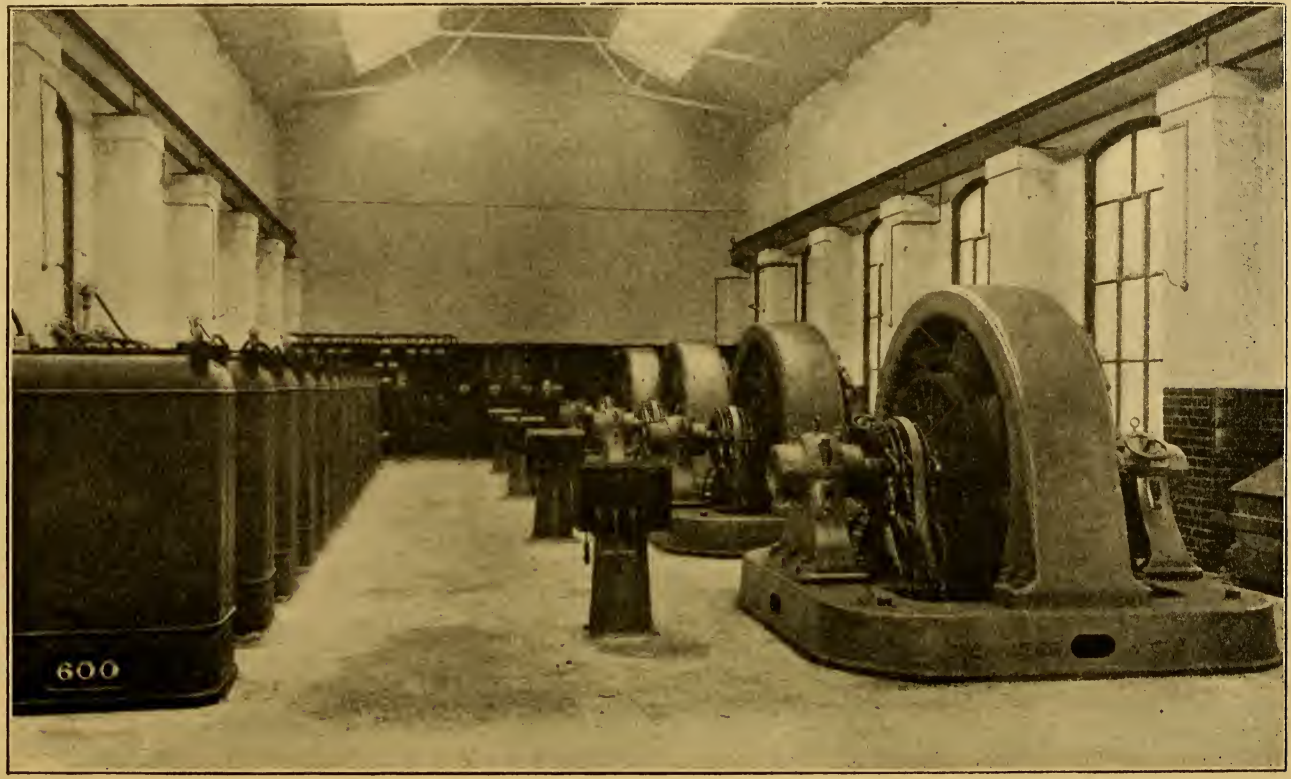


Fig. 174.

traversers, turn-tables, capstans, and a very large electrically operated grain elevator and 20,000-ton silo containing 34 motors aggregating 955 B.H.P.

Railway Substation.—Fig. 174 shows a typical 3000-K.W. railway substation on the Liverpool and Southport Railway, containing rotary converters, each of 600 K.W., with transformers of the air-blast type (three single-phase to each converter). The ventilation is provided by two induction motor-driven blowers, each of 5 H.P. coupled direct to a fan displacing 8000 cubic feet per minute at a pressure of 3 inches. The floor space occupied per K.W. is 1·33 square feet, and the total cubical contents 40 cubic feet per K.W.; the total cost of the substation, including building plant and switchgear, being £6·8 per K.W. installed.

Fig. 175 shows a plan of a typical traction substation as designed for the L.C.C. tramways. In this substation both synchronous and inductor motor generators are installed. The motors are 3-phase star connected with a supply pressure of 6600 volts between phases, and at 252 per second. The generator fields are all shunt wound, and not compounded, in order to simplify the switchgear. The synchronous sets are excited at 125 volts from a direct-current generator mounted on the main shaft. The inductor sets have short-circuited rotors, being started up on the direct current side and switched directly on to the H.T. bus bars at synchronous speed. Synchronous speed is indicated to the attendant by a small enamelled iron disc painted with alternate black-and-white sectors, screwed to the end of the generator shaft. The sectors illuminated by a 25 ~ lamp appear to be stationary when at synchronous speed.

A section of the H.T. switch gear is shown in Fig. 176, and represents as simple and effective a type as can be adopted. The operating panels are on the machine floor, and the H.T. cubicles in the gallery immediately above. Accessibility to parts, safety of operation, inspection and cleaning, and simplicity of design and operation are the salient properties. The cost of a 3000-K.W. substation (of the same type as illustrated in Fig. 175) is given by Mr. Rider as shown in Table No. CXIX., exclusive of the cost of site.

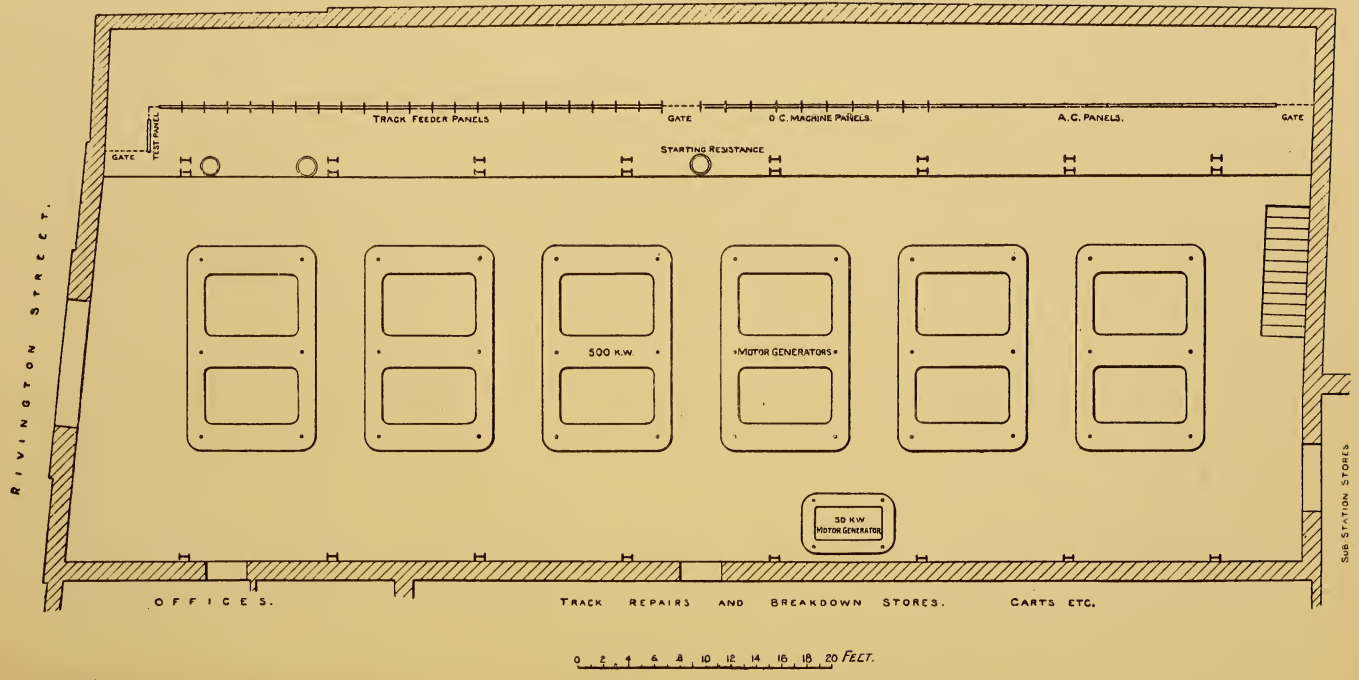

RIVINGTON STREET.
GATE
TEST PANEL
TRACK FEEDER PANELS
GATE
D.C. MACHINE PANELS.
A.C. PANELS.
GATE
STARTING RESISTANCE
500 K.W.
MOTOR GENERATORS
30 K.W. MOTOR GENERATOR
OFFICES.
TRACK REPAIRS AND BREAKDOWN STORES.
CARTS ETC.
SUB STATION STORES
0 2 4 6 8 10 12 14 16 18 20 FEET.

FIG. 175.

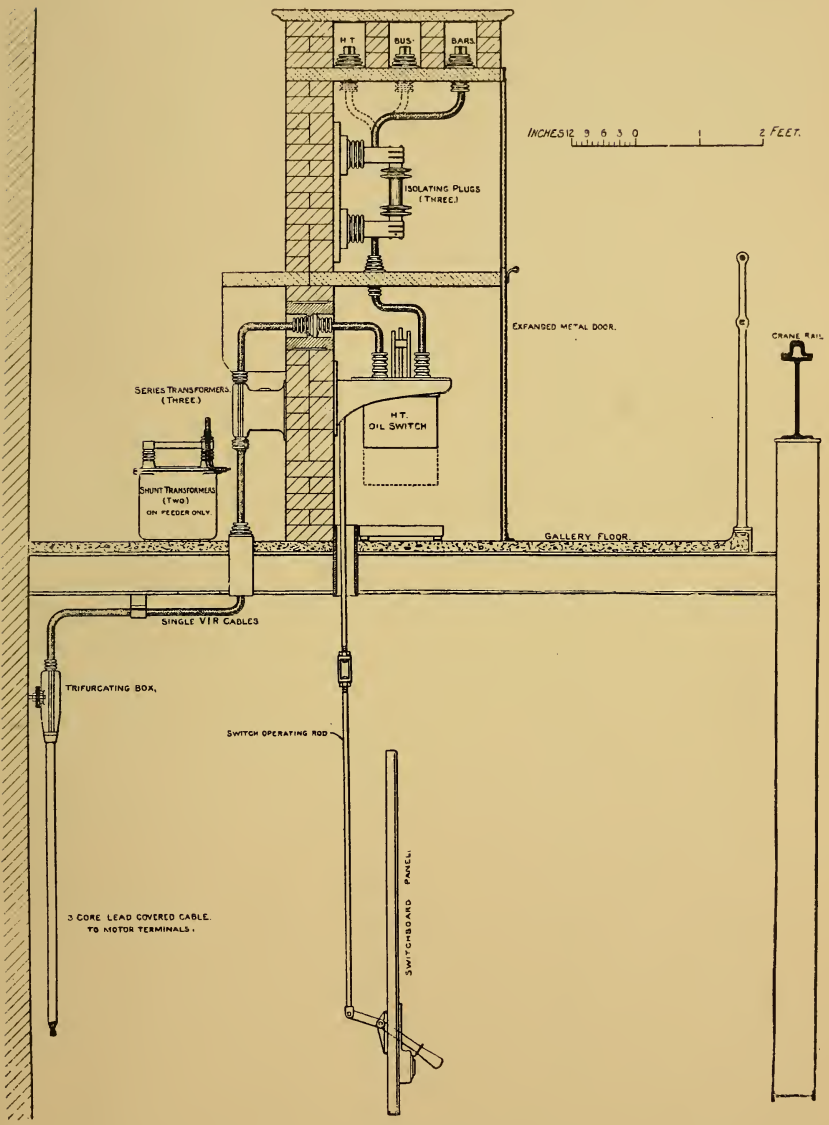

H.T. BUS-BARS.
INCHES 12 9 6 3 0 1 2 FEET.
ISOLATING PLUGS (THREE.)
EXPANDED METAL DOOR.
CRANE RAIL.
SERIES TRANSFORMERS (THREE.)
H.T. OIL SWITCH
SHUNT TRANSFORMERS (TWO) ON FEEDER ONLY.
GALLERY FLOOR
SINGLE VIR CABLES
TRIFURCATING BOX.
SWITCH OPERATING ROD
SWITCHBOARD PANEL.
3 CORE LEAD COVERED CABLE. TO MOTOR TERMINALS.

FIG. 176.

TABLE CXIX.

Item.	Total cost.	Cost per kilowatt.
	£	£
Motor generators	10,400	3·47
H. and L.P. switchgear	3,420	1·14
Crane, tools, lighting, etc.	400	0·13
Bendings	6,520	2·17
Total	20,720	6·91

The diversity of the 23 substations supplying the L.C.C. tramway system, that is, the ratio of the sum of the maximum loads on the separate substations to the observed simultaneous maximum load at the power house, is 1·25.

The annual efficiency of these substations, *i.e.* the ratio of units output to units input is 73·5 per cent. for the synchronous sets, and 82·1 per cent. for the induction motor generator substations.

Combined 3-phase, 4-wire, Transformer and Rotary Substation.—Another typical substation is shown in Fig, 177. This was constructed to the Author's specifications for both the general supply of a town in South America by a 3-phase 4-wire system, and also for a 500-600 volt traction supply through rotaries. The building is of steel framework, with brick panels, and roofing and ceiling beams of eternit sheets. The general supply is from 3-phase 500-K.V.A transformers supplied at a pressure of 6600 volts, 50 ~ with a secondary pressure of 380 volts between phases, and 220 volts between each phase and the neutral.

The street arc lighting is from single-phase constant-current self-regulating transformers.

The traction supply is from four 350-K.W. rotaries, each complete with its own transformer and exciter.

There are three switchboards, all the H.T. work being concentrated on the gallery in cubicles, in a manner similar to Fig. 176. All the operating boards, viz. (*a*) the H.T. operating panels, (*b*) the L.T.A.C. board, and (*c*) the traction 550 volt board, are all on the machine floor-level.

The cost of this substation erected abroad and excluding the site value was as shown in Table No. CXX., the total capacity being K.W. (the transformers being taken at 0·85 P.F. average).

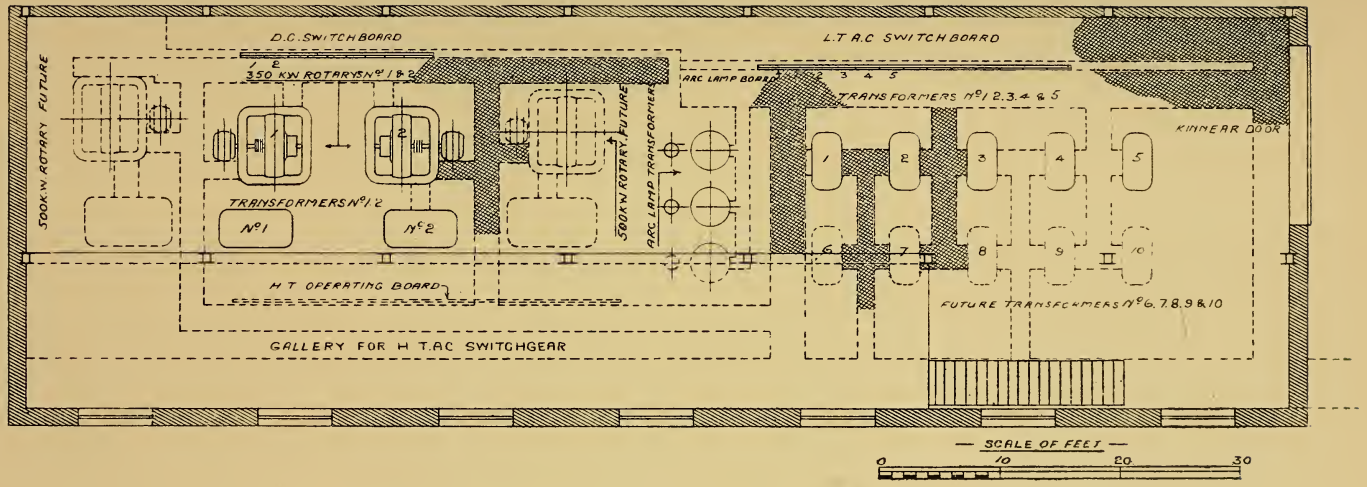

D.C. SWITCH BOARD
L.T.A.C SWITCH BOARD
350 KW ROTARYS Nº 1 & 2
ARC LAMP BOARD
TRANSFORMERS Nº 1 2 3 4 & 5
KINNEAR DOOR
500 K.W. ROTARY FUTURE
TRANSFORMERS Nº 1 2
Nº 1
Nº 2
500 K.W. ROTARY FUTURE
ARC LAMP TRANSFORMERS
H T OPERATING BOARD
FUTURE TRANSFORMERS Nº 6. 7. 8. 9 & 10
GALLERY FOR H T A.C SWITCHGEAR
SCALE OF FEET
0
10
20
30

FIG. 177.

TABLE CXX.

Item.	Total capital cost.	Per K.W. of plant.	Cost per total K.W. installed.
	£	£	£
Buildings	2708		1·02
H. and L.T. switchgear and connecting cables	4878		1·84
5 transformers, 1250 K.W. . . .	955	0·76	
4 rotaries with transformers, 1400 K.W.	4007	2·86	1·87
Crane, tools, lighting, etc. . . .	352		0·13
Total	£12,900		£4·86

A small oil engine plant was shown in Fig. 122, to which reference may be made.

A small gas-engine plant was shown in Figs. 119 and 120, and describes a self-contained producer gas plant for the carriage works at Swindon.

In some cases it will be found cheaper to install a small independent power house, in others to purchase power in bulk from some outside authority. It is largely a matter of relative cost, though the bulk supply alternative has this further recommendation, viz. that the supply is always available and may be switched on when required or switched off if the works are closed. Space —often of great value in older works—is also saved. The present-day tendency is for the managers of works to avail themselves of an outside supply where that is available. Still, there are cases, such as collieries, where small coal is of insufficient commercial value to outsiders, or other kinds of works with exhaust steam or waste gases; others obliged to maintain steam for other purposes, and so forth, where an independent power house is certainly of greater economy to the factory. As the Author has insisted throughout this book, every case must be looked into on its merits. It should be possible, by reference to the various chapters herein, for any engineer to be able to find within reasonably accurate limits, (*a*) the first cost, and (*b*) such information as will (combined with his own local knowledge of the cost of coal, or oil, or gas, as the case may be, and the cost of labour) enable him to determine the probable cost of production.

APPENDIX I.

The Woodeson straight water-tube boilers are made by Messrs. Clarke, Chapman and Co., of Gateshead, England. This boiler is made up of a number of sections, each section consisting of a steam drum at the top, and a water drum at the bottom, and a number of

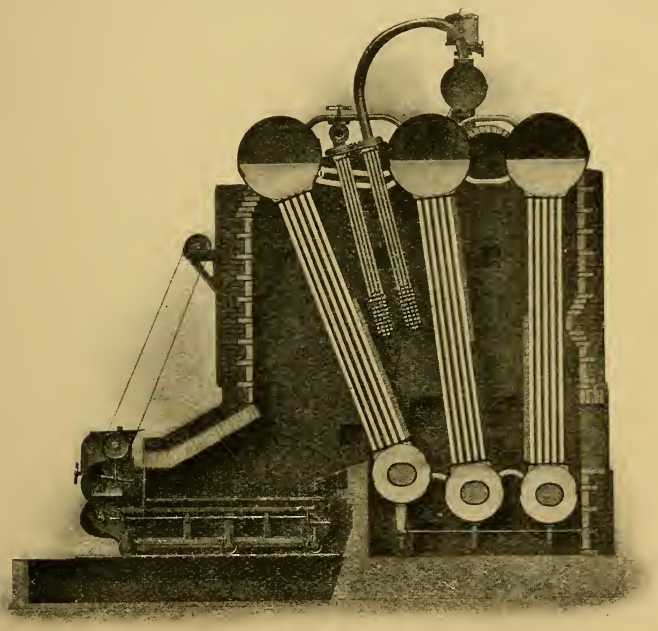


Fig. 178.—Fitted with Chain Grate Stoker.

groups of tubes which varies according to the size of the boiler, as shown in Table No. CXXI. The tubes are expanded into flat discs, which are hydraulically pressed out of the solid plates of both the steam and water drums.

Manholes on the steam drums are arranged over each group of tubes, enabling them to be easily inspected or withdrawn and renewed.

Each steam drum is connected to the neighbouring drum by horizontal circulating pipes; and the water drums are connected in a

similar manner. The whole boiler is suspended from girders, and is entirely free at the bottom to allow for expansion.

The fire-grate is fixed across the boiler and immediately in front of the tube sections as shown in Figs. 179 and 180. The gases travel upwards through the nests of front tubes, over the firebrick baffle which is arranged between the sections, and thence downwards through

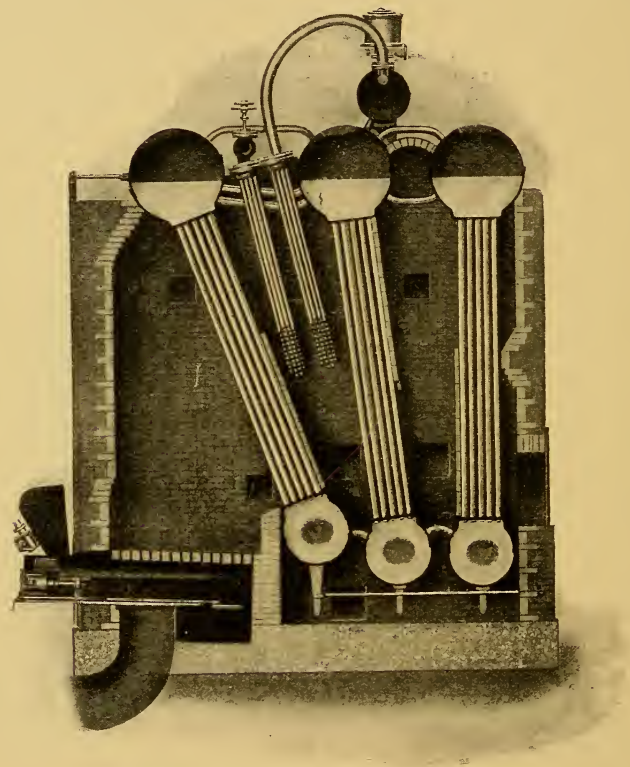


Fig. 179.—Fitted with Underfeed Stoker (with Fan).

the back sets of tubes to the exit damper. The water circulation is from the rear steam drum, where the feed water enters at a point furthest away from the fire, down the back tubes, and up the front tubes. All deposit is thus left in the bottom rear drum, and all tubes in the front sections exposed to the greatest heat have thus only clean water circulating in them.

The following Table, No. CXXI., sets out the leading dimensions, weights, and other particulars of the Woodeson boiler, arranged as in (A) for Underfeed Stokers, and (B) Chain Grate Stokers.

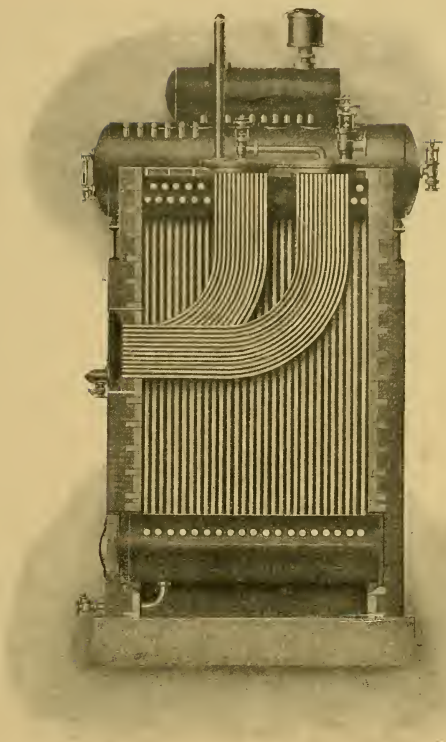


FIG. 180.—Section.

TABLE CXXI.

A.—BOILERS FITTED WITH UNDERFEED STOKERS.

Evaporation per hour f. and a. 212° Fahr.	Heating surface.	Grate area.	No. of sections.	No. of groups of tubes per section.	Shipping.		Overall dimensions.					
					Weight.	Measure.	Height.		Width.		Depth.	
lbs.	sq. ft.	sq. ft.			tons.	cub. ft.	ft.	ins.	ft.	ins.	ft.	ins.
6,555	1350	23	3	2	23	1610	22	9	6	3	21	0
9,690	2025	34	3	3	29	2000	22	9	7	10	21	0
12,825	2700	45	3	4	33	2310	22	9	9	5	21	0
15,960	3450	56	3	5	37	2590	22	9	11	0	21	0
19,380	4050	68	3	6	44	3080	22	9	12	7	21	0
22,600	4750	79	3	7	50	3500	22	9	14	2	21	0
25,650	5400	90	3	8	55	4140	22	9	15	9	21	0

B.—Boilers fitted with Chain Grate Stokers.

Evaporation per hour f. and a. 212° Fahr.	Heating surface.	Grate area.	No. of sections.	No. of groups of tubes per section.	Shipping.		Overall dimensions.					
					Weight.	Measure.	Height.		Width.		Depth.	
lbs.	sq. ft.	sq. ft.			tons.	cub. ft.	ft.	ins.	ft.	ins	ft.	ins.
6,440	1350	28	3	2	27	1710	22	9	6	3	24	0
9,430	2025	41	3	3	36	2260	22	9	7	10	24	0
12,000	2700	52	3	4	41	2570	22	9	9	5	24	0
14,950	3450	65	3	5	48	2950	22	9	11	0	24	0
18,170	4050	79	3	6	53	3200	22	9	12	7	24	0
20,470	4650	89	3	7	62	3790	22	9	14	2	24	0
24,150	5400	105	3	8	69	4200	22	9	15	9	24	0

APPENDIX II.

Circulating Water Pipes.

The following Fig., No. 181, shows graphically the gallons delivered per minute through various diameters of pipe at various velocities. It is usual to design the pipes for a velocity of 5 feet per second, and this is good practice.

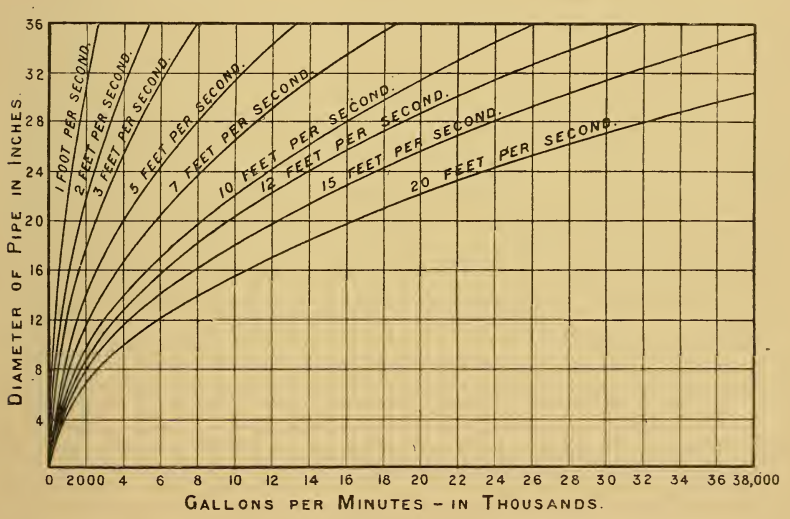


Fig. 181.

For the standard sizes of galvanized circulating pipes, see Table XLIII., p. 138, Chap. V.

APPENDIX III.

ELECTRICITY REGULATIONS (GREAT BRITAIN).

Made under the Factory and Workshop Acts, 1901 and 1907.

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Definitions.

"Pressure" means the difference of electrical potential between any two conductors, or between a conductor and earth, as read by a hot wire or electrostatic volt-meter.

"Low Pressure" means a pressure in a system normally not exceeding 250 volts where the electrical energy is used.

"Medium Pressure" means a pressure in a system normally above 250 volts, but not exceeding 650 volts, where the electrical energy is used.

"High Pressure" means a pressure in a system normally above 650 volts, but not exceeding 3000 volts, where the electrical energy is used or supplied.

"Extra-high Pressure" means a pressure in a system normally exceeding 3000 volts, where the electrical energy is used or supplied.

"System" means an electrical system in which all the conductors and apparatus are electrically connected to a common source of electromotive force.

"Conductor" means an electrical conductor arranged to be electrically connected to a system.

"Apparatus" means electrical apparatus, and includes all apparatus, machines, and fittings in which conductors are used, or of which they form a part.

"Circuit" means an electrical circuit forming a system or branch of a system.

"Insulating stand" means a floor, platform, stand, or mat
"Insulating screen" means a screen
"Insulating boots" means boots
"Insulating gloves" means gloves
} of such size, quality, and construction according to the circumstances of the use thereof, that a person is thereby adequately protected from danger.

"Covered with insulating material" means adequately covered with insulating material of such quality and thickness that there is no danger.

"Bare" means not covered with insulating material.

"Live" means electrically charged.

"Dead" means at, or about, zero potential, and disconnected from any live system.

"Earthed" means connected to the general mass of earth in such manner as will ensure at all times an immediate discharge of electrical energy without danger.

"Substation" means any premises, or that part of any premises, in which electrical energy is transformed or converted to or from pressure above medium pressure, except for the purpose of working instruments, relays, or similar auxiliary apparatus; if such premises or part of premises are large enough for a person to enter after the apparatus is in position.

"Switchboard" means the collection of switches or fuses, conductors, and other apparatus in connection therewith, used for the purpose of controlling the current or pressure in any system or part of a system.

"Switchboard passage-way" means any passage-way or compartment large enough for a person to enter, and used in connection with a switchboard when live.

"Authorized person" means (*a*) the occupier, or (*b*) a contractor for the time being under contract with the occupier, or (*c*) a person employed, appointed, or selected by the occupier, or by a contractor as aforesaid, to carry out certain duties incidental to the generation, transformation, distribution, or use of electrical energy, such occupier, contractor, or person being a person who is competent for the purposes of the regulation in which the term is used.

"Danger" means danger to health or danger to life or limb from shock, burn, or other injury to persons employed, or from fire attendant upon the generation, transformation, distribution, or use of electrical energy.

"Public supply" means the supply of electrical energy (*a*) by any

local authority, company, or person authorized by Act of Parliament or Provisional Order confirmed by Parliament or by licence or Order of the Board of Trade to give a supply of electrical energy; or (*b*) otherwise under Board of Trade regulations.

Exemption 1.

Nothing in Regulations 2, 3, 4, 7, 9, 10, 11, 15, 16, 17, 21, 22, 23, 24, 25, 26, 28, 29, 30, and 31 shall apply, unless on account of special circumstances the Secretary of State shall give notice to the occupier that this exemption does not apply—

(*a*) To any system in which the pressure does not exceed low pressure direct or 125 volts alternating;

(*b*) In any public supply generating station, to any system in which the pressure between it and earth does not exceed low pressure;

(*c*) In any above-ground substation for public supply, to any system not exceeding low pressure.

Exemption 2.

Nothing in these Regulations shall apply to any service lines or apparatus on the supply side of the consumer's terminals, or to any chamber containing such service lines or apparatus, where the supply is given from outside under Board of Trade regulations; provided always that no live metal is exposed so that it may be touched.

Exemption 3.

If the occupier can show, with regard to any requirement of these Regulations, that the special conditions in his premises are such as adequately to prevent danger, that requirement shall be deemed to be satisfied; and the Secretary of State may by Order direct that any class of special conditions defined in the Order shall be deemed for the purposes of all or any of the requirements of these Regulations adequately to prevent danger, and may revoke such Order.

(Under this exemption the Secretary of State has made the following Order, § dated 28th July, 1909:—

In pursuance of Exemption 3 of the above Regulations, I hereby direct that in rooms, other than electrical stations, in which the following special conditions are observed, viz.:—

no electrical energy is used except at low pressure, nor for any purpose other than lighting by means of incandescent lamps; and

the floor is of wood or otherwise insulating; and

there is no machinery or other earthed metal with which a person handling any non-earthed lamp fittings or any portable lamp is liable to be in contact; and

no process rendering the floor wet is carried on; and

no live conductor is normally exposed so that it may be touched;

such conditions shall be deemed for all the purposes of the Regulations adequately to prevent danger.)

Exemption 4.

Nothing in these Regulations shall apply to any process or apparatus used exclusively for electro-chemical or electro-thermal or testing or research purposes; provided such process be so worked and such apparatus so constructed and protected and such special precautions taken as may be necessary to prevent danger.

Exemption 5.

The Secretary of State may, by Order, exempt from the operation of all or any of these Regulations any premises to which any special rules or regulations under any other Act as to the generation, transformation, distribution or use of electrical energy apply; and may revoke such Order.

(No Order has been made.)

Exemption 6.

The Secretary of State may, if satisfied that safety is otherwise practically secured, or that exemption is necessary on the ground of emergency or special circumstances, grant such exemption by Order, subject to any conditions that may be prescribed therein; and may revoke such Order.

(No Order has been made.)

Exemption 7.

Nothing in these Regulations shall apply to domestic factories or domestic workshops.

See Factory Act, 1901, s. 115.

Regulation 1.

All apparatus and conductors shall be sufficient in size and power for the work they are called upon to do, and so constructed, installed,

protected, worked and maintained as to prevent danger so far as is reasonably practicable.

Regulation 2.

All conductors shall either be covered with insulating material, and further efficiently protected where necessary to prevent danger, or they shall be so placed and safeguarded as to prevent danger so far as is reasonably practicable.

Regulation 3.

Every switch, switch fuse, circuit-breaker, and isolating link shall be :—(*a*) so constructed, placed, or protected as to prevent danger ; (*b*) so constructed and adjusted as accurately to make and to maintain good contact ; (*c*) provided with an efficient handle or other means of working, insulated from the system, and so arranged that the hand cannot inadvertently touch live metal ; (*d*) so constructed or arranged that it cannot accidentally fall or move into contact when left out of contact.

Regulation 4.

Every switch intended to be used for breaking a circuit and every circuit-breaker shall be so constructed that it cannot with proper care be left in partial contact. This applies to each pole of double-pole or multipole switches or circuit-breakers.

Every switch intended to be used for breaking a circuit and every circuit-breaker shall be so constructed that an arc cannot accidentally be maintained.

Regulation 5.

Every fuse, and every automatic circuit-breaker used instead thereof, shall be so constructed and arranged as effectively to interrupt the current before it so exceeds the working rate as to involve danger. It shall be of such construction or be so guarded or placed as to prevent danger from over-heating, or from arcing or the scattering of hot metal or other substance when it comes into operation. Every fuse shall be either of such construction or so protected by a switch that the fusible metal may be readily renewed without danger.

Regulation 6.

Every electrical joint and connection shall be of proper construction as regards conductivity, insulation, mechanical strength and protection.

Regulation 7.

Efficient means suitably located shall be provided for cutting off all pressure from every part of a system, as may be necessary to prevent danger.

Regulation 8.

Efficient means suitably located shall be provided for protecting from excess of current every part of a system, as may be necessary to prevent danger.

Regulation 9.

Where one of the conductors of a system is connected to earth, no single-pole switch, other than a link for testing purposes or a switch for use in controlling a generator, shall be placed in such conductor or any branch thereof.

A switch, or automatic or other cut-out may, however, be placed in the connection between the conductor and earth at the generating station, for use in testing and emergencies only.

Regulation 10.

Where one of the main conductors of a system is bare and uninsulated, such as a bare return of a concentric system, no switch, fuse, or circuit-breaker shall be placed in that conductor, or in any conductor connected thereto, and the said conductor shall be earthed.

Nevertheless, switches, fuses, or circuit-breakers may be used to break the connection with the generators or transformers supplying the power; provided that in no case of bare conductor the connection of the conductor with the earth is thereby broken.

Regulation 11.

Every motor, converter and transformer shall be protected by efficient means suitably placed, and so connected that all pressure may thereby be cut off from the motor, converter or transformer as the case may be, and from all apparatus in connection therewith; provided, however, that where one point of the system is connected to earth, there shall be no obligation to disconnect on that side of the system which is connected to earth.

Regulation 12.

Every electric motor shall be controlled by an efficient switch or switches for starting and stopping, so placed as to be easily worked by the person in charge of the motor.

In every place in which machines are being driven by any electric motor, there shall be means at hand for either switching off the motor or stopping the machines if necessary to prevent danger.

Regulation 13.

Every flexible wire for portable apparatus, for alternating currents or for pressures above 150 volts direct current, shall be connected to the system either by efficient permanent joints or connections, or by a properly constructed connector.

In all cases where the person handling portable apparatus or pendant lamps with switches, for alternating current or pressures above 150 volts direct current, would be liable to get a shock through a conducting floor or conducting work or otherwise, if the metal work of the portable apparatus became charged, the metal work must be efficiently earthed; and any flexible metallic covering of the conductors shall be itself efficiently earthed and shall not itself be the only earth connection for the metal of the apparatus. And a lampholder shall not be in metallic connection with the guard or other metal work of a portable lamp.

In such places and in any place where the pressure exceeds low pressure, the portable apparatus and its flexible wire shall be controlled by efficient means suitably located, and capable of cutting off the pressure, and the metal work shall be efficiently earthed independently of any flexible metallic cover of the conductors, and any such flexible covering shall itself be independently earthed.

Regulation 14.

The general arrangement of switchboards shall, so far as reasonably practicable, be such that—

(*a*) All parts which may have to be adjusted or handled are readily accessible.

(*b*) The course of every conductor may where necessary be readily traced.

(*c*) Conductors, not arranged for connection to the same system, are kept well apart, and can where necessary be readily distinguished.

(*d*) All bare conductors are so placed or protected as to prevent danger from accidental short circuit.

Regulation 15.

Every switchboard having bare conductors normally so exposed that they may be touched, shall, if not located in an area or areas set apart for the purposes thereof, where necessary be suitably fenced or enclosed.

No person except an authorized person, or a person acting under

his immediate supervision, shall for the purpose of carrying out his duties have access to any part of an area so set apart.

Regulation 16.

All apparatus appertaining to a switchboard and requiring handling, shall so far as practicable be so placed or arranged as to be operated from the working platform of the switchboard, and all measuring instruments and indicators connected therewith shall, so far as practicable, be so placed as to be observed from the working platform. If such apparatus be worked or observed from any other place, adequate precautions shall be taken to prevent danger.

Regulation 17.

At the working platform of every switchboard and in every switchboard passage-way, if there be bare conductors exposed or arranged to be exposed when live so that they may be touched, there shall be a clear and unobstructed passage of ample width and height, with a firm and even floor. Adequate means of access, free from danger, shall be provided for every switchboard passage-way.

The following provisions shall apply to all such switchboard working platforms and passage-ways constructed after January 1st, 1909, unless the bare conductors, whether overhead or at the sides of the passage-ways, are otherwise adequately protected against danger by divisions or screens or other suitable means:—

(*a*) Those constructed for low-pressure and medium-pressure switchboards shall have a clear height of not less than 7 ft., and a clear width measured from bare conductor of not less than 3 ft.

(*b*) Those constructed for high-pressure and extra high-pressure switchboards, other than operating desks or panels working solely at low-pressure, shall have a clear height of not less than 8 ft., and a clear width measured from bare conductor of not less than 3 ft. 6 in.

(*c*) Bare conductors shall not be exposed on both sides of the switchboard passage-way unless either (i) the clear width of the passage is in the case of low-pressure and medium-pressure not less than 4 ft. 6 in., and in the case of high-pressure and extra high-pressure not less than 8 ft., in each case measured between bare conductors, or (ii) the conductors on one side are so guarded that they cannot be accidentally touched.

Regulation 18.

In every switchboard for high-pressure or extra high-pressure :—

(*a*) Every high-pressure and extra high-pressure conductor within reach from the working platform or in any switchboard passage-way shall be so placed or protected as adequately to prevent danger.

(*b*) The metal cases of all instruments working at high-pressure or extra high-pressure shall be either earthed or completely enclosed with insulating covers.

(*c*) All metal handles of high-pressure and extra high-pressure switches, and, where necessary to prevent danger, all metal gear for working the switches, shall be earthed.

(*d*) When work has to be done on any switchboard, then, unless the switchboard be otherwise so arranged as to secure that the work may be carried out without danger, either (i) the switchboard shall be made dead, or (ii) if the said switchboard be so arranged that the conductors thereof can be made dead in sections, and so separated by permanent or removable divisions or screens from all adjoining sections of which the conductors are live, that work on any section may be carried out without danger, that section on which work has to be done shall be made dead.

Regulation 19.

All parts of generators, motors, transformers, or other similar apparatus, at high-pressure or extra high-pressure, and within reach from any position in which any person employed may require to be, shall be, so far as reasonably practicable, so protected as to prevent danger.

Regulation 20.

Where a high-pressure or extra high-pressure supply is transformed for use at a lower pressure, or energy is transformed up to above low-pressure, suitable provision shall be made to guard against danger by reason of the lower pressure system becoming accidentally charged above its normal pressure by leakage or contact from the higher-pressure system.

Regulation 21.

Where necessary to prevent danger, adequate precautions shall be taken either by earthing or by other suitable means to prevent any metal other than the conductor from becoming electrically charged

REGULATION 22.

Adequate precautions shall be taken to prevent any conductor or apparatus from being accidentally or inadvertently electrically charged when persons are working thereon.

REGULATION 23.

Where necessary adequately to prevent danger, insulating stands or screens shall be provided and kept permanently in position, and shall be maintained in sound condition.

REGULATION 24.

Portable insulating stands, screens, boots, gloves, or other suitable means shall be provided and used when necessary adequately to prevent danger, and shall be periodically examined by an authorized person.

REGULATION 25.

Adequate working space and means of access, free from danger, shall be provided for all apparatus that has to be worked or attended to by any person.

REGULATION 26.

All those parts of premises in which apparatus is placed shall be adequately lighted to prevent danger.

REGULATION 27.

All conductors and apparatus exposed to the weather, wet, corrosion, inflammable surroundings or explosive atmosphere, or used in any process or for any special purpose other than for lighting or power shall be so constructed or protected, and such special precautions shall be taken as may be necessary adequately to prevent danger in view of such exposure or use.

REGULATION 28.

No person except an authorized person or a competent person acting under his immediate supervision shall undertake any work where technical knowledge or experience is required in order adequately to avoid danger; and no person shall work alone in any case in which the Secretary of State directs that he shall not. No person except an authorized person, or a competent person over 21 years of age acting under his immediate supervision, shall undertake any repair, alteration, extension, cleaning, or such work where technical knowledge or experience is required in order to avoid danger, and no one shall do such work unaccompanied.

Where a contractor is employed, and the danger to be avoided is under his control, the contractor shall appoint the authorized person, but if the danger to be avoided is under the control of the occupier, the occupier shall appoint the authorized person.

Regulation 29.

Instructions as to the treatment of persons suffering from electric shock shall be affixed in all premises where electrical energy is generated, transformed, or used above low pressure; and in such premises, or classes of premises, in which electrical energy is generated, transformed or used at low pressure, as the Secretary of State may direct.

Regulation 30.

Every sub-station shall be substantially constructed, and shall be so arranged than no person other than an authorized person can obtain access thereto otherwise than by the proper entrance, or can interfere with the apparatus or conductors therein from outside, and shall be provided with efficient means of ventilation and be kept dry.

Regulation 31.

Every sub-station shall be under the control of an authorized person, and none but an authorized person or a person acting under his immediate supervision shall enter any part thereof where there may be danger.

Regulation 32.

Every underground sub-station not otherwise easily and safely accessible shall be provided with adequate means of access by a door or trap-door, with a staircase or ladder securely fixed and so placed that no live part of any switchboard or any bare conductor shall be within reach of a person thereon: Provided however that the means of access to such sub-station shall be by a doorway and staircase (*a*) if any person is regularly employed therein, otherwise than for inspection or cleaning, or (*b*) if the sub-station is not of ample dimensions and there is therein either moving machinery other than ventilating fans, or extra high pressure.

APPENDIX IV.

Standard Natural Draught Chimney Cooling Towers.

Steam condensed per hour	Circulating water per hour.	Ground space.		Total height.	Approximate foundations.		Approximate weight.	
		Length.	Width.		Excavation.	Concrete.	Dry.	Wet.
lbs.	gallons.	ft.	ft.	ft.	cub. yds.	cub. yds.	tons.	tons.
10,000	40,000	26	24	60	160	54	23·5	25·5
15,000	60,000	37	24	65	230	74	32·5	35·0
20,000	80,000	48	24	65	299	94	40·0	43·5
30,000	120,000	69	24	65	430	132	55·0	59·0
40,000	160,000	91	24	70	565	171	71·0	76·0
50,000	200,000	113	24	70	702	211	87·0	93·0
60,000	240,000	134	24	75	832	249	103·0	110·0
70,000	280,000	156	24	75	970	289	119·0	128·0
75,000	300.000	168	24	80	1040	310	129·0	139·0

The approximate cost of this type of tower is £27 per 1000 lbs. of steam condensed per hour.

APPENDIX V.

The following tests taken of Hall's compound boiler feed pumps will be useful for reference, and confirm the specification given on p. 113 :—

A. Test of Pump, 11″ × 18″ × 10½″ × 24″ Stoke, with Saturated Steam.

Boiler pressure.	Pressure on pump.	Duration of test.	Total No. of double strokes.	Weight of steam used.	Weight of water delivered.	Water delivered per lb. of steam used.
lbs.	lbs.	mins.		lbs.	lbs.	lbs.
200	225	10	145	168	19,700	117
200	200	10	130	140	17,600	125

B. Test of Pump, 9″ × 13¾″ × 8½″ × 18″ Stroke, with Saturated Steam.

160	165	10	174	99	11,842	119·6
160	170	10	144	81	9,801	120

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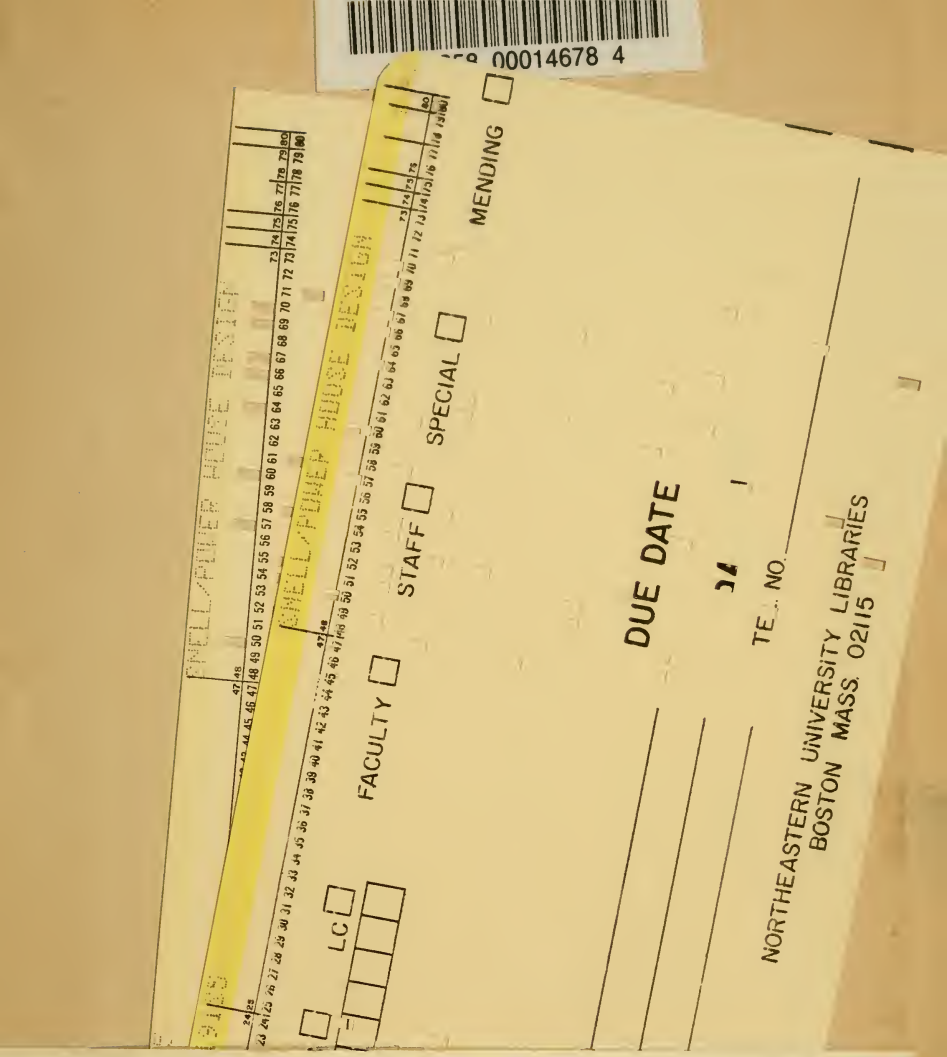

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